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Sundials – Old and New

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SUNDIALS
OLD AND NEW

or Fun with the Sun



A. P. HERBERT

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A. P. H.

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Foreword

by Lieutenant-Commander D. W. Waters, R.N., F.R.HIST.S., F.R.A.S.

This book, *Sundials – Old and New*, is a good book. Its aim is described by the author as 'to make the sundial up to date'. But, as the reader will find out for himself, it is more than that, it is also to give people fun making and using sundials.

People who have admired sundials and wondered how they were constructed can here find out; furthermore, they will find out simple ways of making sundials. Those who have thought about sundials and dismissed them as 'out of date' and impracticable 'toys' will, after reading this book, think again; they will do more than that, they will be fired with enthusiasm to make sundials and to experiment with them as useful 'tools'; 'tools' to have about their home and, if they are sailors, whether amateur or professional, to carry with them at sea. Survival-at-sea kits should certainly include Herbert navigational dials. It is to be hoped that their utility will be brought to the notice of the appropriate authorities. The Herbert dials incorporate a number of novel dialling features first discovered by Sir Alan who, for all his modest disclaimers, is an expert diallist or, as he would say, skialogist. I write this tribute with conviction because he has learnt about dialling from personal observation and experiment and, as many before me have observed, this is the surest way for a man to make himself an expert.

Ten years ago I spent several months as a patient in a sanatorium in Sussex. This is apt to be a slothful existence so, as soon as a patient is beginning to get up and about, he (or she) is introduced to occupational therapy. The first problem he has to tackle is to decide what to make – for doing something with the hands (other than writing, which, hitherto, had kept me occupied) is the essence of this preparation for facing the outside world boldly once again. I had been studying for some years the history of the art of navigation in the age of the great discoveries and I had some of the material with me. Amongst it was an illustration, from the first manual of navigation to be printed in English, of a circular sundial. This instrument, the learned Spanish author of the work, Martin Cortes, claimed could be made by a simple sailor and be used by him to tell the time by the Sun, wherever he voyaged over the world. I decided that, being a simple sailor myself, I need look

no farther for my therapeutical occupation, but would make a similar sundial with my own hands. The dial was what is now known as a universal equinoctial (or equatorial) dial, and it is one of those explained in this book. Martin Cortes's woodcut of it, published in his *Breve Compendio de la Sphera y Arte de Navegar* at Seville in 1551 is, I believe, the earliest illustration of such a dial. It was no coincidence that it was first published in Spain in the middle of the sixteenth century in a book originally intended for Spanish seamen. Seville was the technological as well as the economic and administrative brain-centre of the great sea-divided-ship-knit Spanish empire. Ever since their discovery in 1492 of what had turned out to be a new world, the Spaniards, with great energy and with the aid of the art and science of oceanic navigation, had been colonizing and discovering more and more of it, and of the round world. Just as it had been a Spanish-sponsored expedition which had been the first to find the New World so it had been a Spanish expedition which, less than thirty years later, had first circumnavigated the globe. This had been no accidental feat but a triumph of careful planning and technological ingenuity, preparation and execution, in its day quite as impressive as the launching of the first manned satellite into space was in ours. It was so because it, too, had involved the solution of unprecedented technological problems. One had been how to enable the mariner to tell the time wherever he might be – and this was eventually solved by inventing the universal equinoctial dial (that is, the usable-all-over-the-world sundial) for him, the making of an early pattern of which Martin Cortes described; another had been how to enable the navigator to determine his longitude – his distance east or west from some known place. This problem they never did solve: it was eventually solved in the eighteenth century by two Englishmen, John Hadley and John Harrison. Hadley invented the reflecting quadrant, whence the modern sextant, Harrison a very ingenious spring-driven marine time-keeper, whence the chronometer. Meanwhile seamen had to guess their longitude and rely largely on the Sun to tell their time at sea. The universal equinoctial dial was their great stand-by.

I duly made my universal equinoctial sundial, and in much the same way I am happy to say, as A. P. Herbert made his first dial. I used a piece of white cardboard (for the dial and its stand), a short length of wire (as a gnomon) and two pins (as hinges) – and I used a pencil, a ruler, a protractor and a compass for drawing it out, and a pocket knife for cutting it out. And it worked – eventually! For I knew so little about sundials that at first I did not believe Cortes's instructions and I could

not get the dial to tell the time. This was because it was midwinter when I made it and the shadow of the gnomon was cast, to my perplexity, on the underside of the dial. I found the solution by experiment and after re-reading Cortes carefully. So I proved for myself that, in order to learn about dialling, as about any other skill, 'practice is the best'.

Later, when I got home, I made a horizontal – garden type – dial, again (like A. P. H.) in cardboard, just for the fun of it and, I must admit, to impress my family with my dialling skill.

In the sixteenth and seventeenth centuries books on dialling proliferated. Even in the eighteenth century quite a lot were written. Apart from the fact that these books are expensive to buy, if you can find them, their descriptions of how to make dials of various sorts are usually far from easy to follow. As A. P. Herbert found, they are either too wordy, or their mathematical notations are obscure. Also the problem of the equation of time is seldom dealt with and that of British Summer Time did not, of course, exist when any of these books were written. These are good reasons why *Sundials – Old and New* was written. *Sundials – Old and New* sorts all these problems out, explains how to make dials simply, and to use them intelligently – both on land and at sea. I am quite sure that anyone who starts to make a Herbert dial will not only succeed but, in doing so and having done so, will have fun with the Sun.

D. W. W.

23rd March 1965

Department of Navigation & Astronomy,
National Maritime Museum
Greenwich

Introduction

'I have here the remains of a mutilated cigar-box. There are also a knitting-needle, two sewing-needles, three small protractors costing 1s. 6d. each, the blunt end of a Biro pen, a nameless object I found in the medicine-cupboard, some bits of wood I pinched from the filing-system, two small hinges, a good many small screws, a circular piece from the cover of a blue exercise-book and a circle of hardboard. With this instrument I can tell the time, and find the altitude of the sun – and I have just established, approximately, the latitude and longitude of the place in which we are.'

'Here is a later manufacture, with which I can do better than "approximately". Better models still will be made, I hope, by professionals: and with these, as you will see, if you bear with me to the end, I offer to navigate the *Discord* or the *Shooting Star*. See how I handle the first voyage of the *Discord* to San Francisco.'¹

It is an old maxim of one of my professions that you should try to arrest attention with your first utterance. So I begin with this frantic boast, which shall be developed and explained, for the instruction of young and old.

I forget when, and why, I constructed my first sundial. But I know very well how I became interested in the heavenly bodies. I had a smattering of the stars in the 1914–18 War when I was 'Scout Officer' of my battalion. (That appointment came to an end on the Gallipoli Peninsula, when, a sufferer from hay-fever, I sneezed loudly three times in No Man's Land and roused the Turks to Rapid Fire.) I could go round the sky in a lordly way – The Bear, Arcturus, Vega, Altair, Deneb, Capella and the Pleiades, Pegasus, Orion, Cassiopeia and so back to the Great Bear and the North Star. In France, opposite Lens, one day, Brigade and Corps Intelligence gave warning of a new and devilish device of the Germans, a light now green, now red, over Square This and That, on the map. I was able that evening to identify the mysterious light as the star Capella. The warning was not repeated, and I became Scout Officer again.

The second Great War (I seem to remember that the 1914 affair was also 'Great'

¹ page 179.

at the time) led me farther and deeper into the firmamental mire. As I have related in *Independent Member*, a dear old lady wrote to me in the second year of the war and asked if I would like to have the sextant of her husband, a sea-captain, who had gone down in his ship. I said gratefully 'Yes'. She sent it, saying: 'I shall be glad to know that it is in the hands of a real sailor.'

I blushed at that, for, though I had done much tideway and coastal sailing, I had never found my way about the open seas, except in a liner, and I hardly knew a sextant from a slide-rule. But now I was in the Navy again and, bless me, in command of a ship, H.M. Patrol Vessel *Water Gipsy* — on the Tideway of the Thames. (For a few glorious days at the beginning my patrol orders were addressed to Petty Officer in charge H.M.S. *Water Gipsy*.) I thought that the least I could do was to learn something and try to live up to my gracious lady's words.

Our duties, for the first three or four years, kept us very busy: but I bought many books and in spare moments began my education. At Winchester I had been weaned from mathematics just before I came to logarithms. What a mistake! I found them fascinating and passed on bravely to the fringes of trigonometry, and the Spherical Triangle. I used chiefly Norie's *Epitome*, C. A. Lund's excellent *Navigation for Yachtsmen*, and Reed's *Nautical Almanac*.

So there I was, with a ship, a sextant, and a good deal of self-taught paper knowledge. I was still a little vague about the nature of a cosine or cosecant (I am still) but I knew where to look the fellows up and how to use them in a Marcq St Hilaire or longitude working. I was all ready to navigate the seas and do my lady credit. The only thing was I had no sea. I was confined to the tidal Thames and except in Sea Reach (the last reach of the Thames) could hardly ever get a 'horizon' more than a mile away. (If your 'height of eye' is 10 feet it should be $3\frac{1}{2}$ miles.) Sea Reach can be pretty rough for a small boat, but I did twice get my longitude there, while on patrol, within 300 yards.

Then I read somewhere that it was possible to use a 'shore horizon', or short horizon, with a special allowance for dip (that means the 'dip of the horizon', the angle you must subtract from your 'observed altitude' according to your 'height of eye', your own height above the sea).

I had no book then which told me how to find the 'dip', so, bless me, I invented a formula of my own. This is no use to the dialler but I give it for the sake of students or yachtsmen who want to practise their sights and sums at home, which is a very good thing to do.

It is very simple: log height of eye (in feet) *minus* log horizon (in feet) = log tan A = the dip.

Say your H.E. is 20 feet and your 'horizon', the point where you 'bring down the Sun', is half a mile away:

$$\begin{array}{rcl} \text{Log} & 20 & = 1.30103 \\ \text{Log} & 3040 & = 3.48287 \\ \hline \text{Log tan } A & & = 7.81816 = 22' 38'' \text{ Dip} \end{array}$$

The Admiralty Manual (Vol. III) gives another and much more complicated formula:

$$\theta = 0.565 \frac{H}{d} + 0.423d$$

This is hideous labour, and the result, in the circumstances above, is only 10 seconds of arc different from mine (22' 48").

So, with respect, I still use mine. With this formula I had great fun. Waiting for the blitz, or counting doodle-bugs, I would 'bring down' Venus to the other side of the Pool of London. I once tried towing a lifebuoy on a measured string, and brought the Sun down to that: but we got across the river in Erith Rands, a tug cut my string, and we lost our lifebuoy for a time. The wildest experiments and the wrongest results were instructive, taught me something about the use of the sextant, and the way about the books, and made the formulae familiar. I still, now and then, walk to the bottom of my garden at Hammersmith, bring down the Sun to the opposite bank and 'get my latitude'. It is not always quite right, but it is a satisfying act.

Mockers used to say: 'What is the use of proving that you are where you knew you are?' One answer is, There are very few people in London who could do it. 'Also,' I said, 'I am preparing for a day when I may not know where I am.' This came in 1943 when Mr Attlee sent me with two other M.P.s to visit Newfoundland. We travelled up the coast of Labrador among the icebergs and the whales in a small sailing-vessel of about 60 tons. My colleagues flew back from Goose Bay. I stayed with the Newfoundlanders in the boat. On the voyage back to Newfoundland we were driven by storm and fog into one of the tiny islands, all exactly

alike, that fringe that formidable coast. There we lay, fogbound, for nine solid days, very cold and eating salt cod and seagulls (I must say I preferred the seagulls). Nobody knew exactly where we were. The Newfoundland skipper, a very fine seaman, thought we were in a certain cove in the Seal Islands. His brother, the mate, thought we were farther north, in the Duck Islands. On the seventh day, for about five minutes, the Sun showed through a hole in the mist. It was over the land and would have been no use to the normal navigator. But there was I, equipped with my Thames technique and my home-made formula for 'dip'. I dashed to my cabin for the sextant, much to the amusement of the Newfoundlanders, and slightly to their alarm, for there were some who said superstitiously that I had already 'shot the Sun' out of the sky. I took a sight 'bringing down the Sun' to the shore of the cove, 400 yards away, as I judged. Assuming that we were where the captain thought I worked a Marcq St Hilaire and got an intercept of 15" (a position line, that is, about 270 yards from where we thought we were). As a check I worked the sight for latitude and longitude and was 30" and 10" away. Experts of course loftily maintain that you cannot get a 'fix' with a single sight. In all the circumstances I believe I did. My single line was not through the Duck Islands or the Partridge Islands, but the Seal Islands. At all events, I confidently told the captain that he was in the Punch Bowl, Seal Islands, as he supposed. And so he was. They then sent the small boat through the fog to another island for stores. 'So,' I said to my distant mockers, 'there!'

I reported all this with pride to my crew, then a Yorkshire fisherman and a plumber, when I got back to London. It was a pleasing point that all my simple companions took a keen interest in my astronomical antics. We used to sit at round tables at the pubs, and with rotating beer-mugs and revolving glasses I would try to explain the behaviour of the Heavens. Later in the war a young butcher was the keenest of all. He learned to take a noon sight and work it out. I have always found that simple folk are interested in these high affairs if they are given half a chance. But, as a rule, they get small encouragement, and expressions like Right Ascension frighten them away.

All this round-table instruction in pubs led me to devise a Star Clock. It began as two rough bits of cardboard, one moving, which showed my crew the stars going round the Earth and explained the Right Ascension, the Greenwich Hour Angle, and so on. It developed into a grand affair in ivory perspex. It shows over what meridian any star is standing at any particular minute. For example, I can

show you what bright stars were over Palestine on the evening of December 25 (if that was the real date of Christmas). They were Sirius and Canopus, the two brightest stars in the sky. My Star Clock shows sidereal (or star) time as well as Sun Time, so it is a quick and easy way of setting the Star Globe, which every ship's navigator uses, to find what stars will be about at twilight, when he takes his evening sights. In some spare moment let him set the Star Globe accordingly for the latitude of Bethlehem ($31^{\circ} 42' 11''$) and for the sidereal time of about 6.20. The meridian of his globe will then be the meridian of Bethlehem (Longitude $35^{\circ} 12' E$): and he will see Canopus is 'standing' over it, low over the horizon, about 7 degrees up. Sirius is to the East, 20 minutes behind him, at an altitude of 41° . The time, by my Star Clock, is 9.52 Greenwich Mean Time or 7.32 Local Mean Time on 25 December, a reasonable hour for the Wise Men to begin their southward march from Jerusalem to Bethlehem. And, by the way, if the true date, as some insist, was January 6, they would have seen the same concatenation of events at about 7 p.m. Sunset would be about 5.0.

You remember the story? 'There came wise men from the east to Jerusalem, saying: "Where is he that is born King of the Jews for we have seen his star in the east and are come to worship him?"' (Matthew ii.2).

(By this they meant, clearly, that they saw the star when *they* were in the East. It is necessary to emphasize this because of those ludicrous carols which give a picture of the Wise Men coming from the East to Jerusalem led by a star in the Eastern sky, which they could only see by looking over their shoulders. It was not a star in the East, as the carols ridiculously say, but a star in the South.)

'When they had heard the King' (Herod) 'they departed' (to Bethlehem): 'and lo, the star *which they saw in the east*, went before them till it came and *stood* over where the young child was' (Matthew ii.9).

'Stood'. - Bethlehem ($35^{\circ} 12' E$) is due South of Jerusalem ($35^{\circ} 13' E$). 'Stand' is the verb which has been used for ages to describe the posture of a heavenly body which has reached its culminating point and is 'over the meridian'. It is clear that whatever the Wise Men had seen in the East it was standing over Bethlehem that night. This fits, for the stars move on each night, four minutes, from East to West.

Now where did the Wise Men come from? I suppose they came from the great Assyrian and Babylonian Plain between the Tigris and the Euphrates? Nineveh? Asshur, the original capital? The Babylonians were great students of the stars and

are said to have started the sundial. Wherever they lived in the Plain they would be old friends of Sirius, the senior star, who dwells to the East of Orion, almost in line with his Belt. But Canopus — no. To ascertain how far North or South a star is visible you must deduct the Declination (distance from the Equator, see page 39) from 90° . The declination of Sirius is only 16° South so he comes to Hammer-smith every Christmas and stays with us for many months — I saw him first this year, well up, on 12 November.

But the declination of Canopus is $52^\circ 40'$ South. Take that from 90° and $37^\circ 20'$ is left. So, except at sea perhaps, for a brief span on a clear night, you will never see Canopus in Latitude $36^\circ 21'$ (Nineveh) or even $35^\circ 30'$ N (Asshur) — especially if there are hills or mountains in the South. The merest bush would intervene.

But perhaps some travellers went South and climbed the hills and saw this great new star, with their old friend Sirius, almost vertically over him, and thus its fame began.

On their long journey — 500 to 600 miles — to Jerusalem they would for the most part have the high ground of the Syrian desert to the South, and may not have seen Canopus again till they drew near to Jerusalem.

I have often thought it remarkable that, with all that vast 'firmament' to play with, the Creator chose to put the two brightest stars so close together. It would be fitting if it was these two that 'stood over where the young child was'.

There are other theories, I know (some of them are exhibited, I believe, at the London Planetarium). A 'conjunction' of two planets — Jupiter and Saturn? But then surely the fable would have been not of one bright luminary, but two — much more remarkable? A blazing 'nova' — an old star which seems suddenly to explode? A comet? But any such special wonder would have been clearly visible from the home of the Magi — there would have been no need to chase it across the desert.

To me Canopus only seems to fit all the facts. No other bright star, in all the year passes so low, and 'stands' so intimately, over Bethlehem: and my theory at least explains why, to the Magi, a normal star might be new and abnormal. It was not normal where they lived: and the nearness of great Sirius would fortify their wonder. The two senior stars would straddle the village.

Last Christmas night (1964) with my Star Clock and Star Globe, I predicted accurately enough where Sirius would be at three different times, ending with his transit over the meridian, which I made 0.32 on the 26th. I don't suppose I was

dead right, but I am quite sure that Canopus was over Bethlehem 2 hours and 20 minutes earlier.

But were Sirius and Canopus there 1964 years ago? An expert tells me that they change their positions by 2 seconds of arc in 3600 years. They have been there every Christmas since the first Christmas. Why look for comets?

So far, I am the only member of the Canopus Club. A fond fancy, it may be. But see what my Star Clock can do! (And see into what fascinating corners amateur astronomy may lead you!) The captain of one liner said it might be very useful, and I should 'do something with it'. I never did.

In 1942 I was sick for a week or two, and, convalescing, I sat up in bed and re-named the stars. I still maintain that this is a good notion. What is wrong, you say, with the old romantic names which have served the stars so long? They are for the most part inept, unfitting, unworthy of the stars and the human race – and therefore do not excite our interest as they should. They are unrelated, meaningless, difficult to distinguish, pronounce and remember – and therefore do not assist the student. 'But,' you say, 'Orion – the Great Bear – Andromeda – Perseus – how beautiful!' (Such things, by the way, are always said by literary people who do not, in fact, know one star from another.) But these are the names of constellations, not stars: and it is stars the navigator uses. Puffed up, no doubt, by my own studies, I used to teach my crew the principal stars: and, indeed, they were often practically useful on short courses in Sea Reach. But the Arabic names were always a trouble. Take 'Betelgeuse', one of the big stars in Orion. It means, they say, 'Armpit of the Central One', and God knows how it should be pronounced. The sailors call it 'Beetle-juice'. How romantic! Take 'Benetnasch' ('Chief of the Mourners'), the tail-star of the Bear (Plough, or Dipper), or 'Dubhe', at the other end – and how do you pronounce that? An old salt quarrelled with me harshly in a nautical journal: how dare I try to meddle with such 'old romantic' names as 'Alpheratz' (in Andromeda), bestowed by the Arabs before the Greeks knew one star from another – and so on. Well, according to one of the big books I studied, the meaning of Alpheratz is 'Horse's Navel', though some have offered other meanings. Whatever it means, it was just Arabic to my crew. 'Fomalhaut', one of the finest stars, means 'The Fish's Mouth', and 'Diphda' 'The Second Frog', they say. The airmen, at least, are on my side, for in the *Air Almanac* they have already cut down some of the larger names – 'Benetnasch' is 'Benet', and 'Arcturus', 'Arctus' –

and since the 'old, romantic' names have no meaning for them they mutilate them without shame. Take a child on to the lawn and tell him: 'That is "Betelgeuse" — and that is "Alnilam"'; and he will yawn. But tell him 'That is "Nelson" — and that is "Columbus"', and he may be interested and look again. That is the general line of my 'reform': have done with 'Hen's Beaks' and 'Fish's Mouths' and 'Horse's Navels', and relate the fine stars to the human race and the best things in human history. I gave a constellation to almost every nation — a little rash, that, I agree, and not essential to the general scheme. The Great Bear went to Britain, and Leo to Russia (for Leo is much more like a Hammer and Sickle than it is like a lion). Then I divided the Heavens into two main sections — Men of Action and Men of Mind. Orion, for example, became 'The Sailor', as follows:

Betelgeuse (Armpit of the Central One)	Nelson
Rigel (Left Leg of the Jauzah)	Drake
Bellatrix (Amazon)	Hawkins
Saiph (Sword)	Magellan
Mintaka (Belt)	Cook
Alnilam (String of Pearls)	Columbus (The Belt)
Al Nitak (Girdle)	Cabot
Nair al Saif	Da Gama

I did my best to be internationally fair in selecting heroes fit for the Heavens: and, no doubt, Unesco, or some committee of astronomers, would do even better. Among the constellations of the Men of Mind — the Poet, the Painter, the Music-maker, Science, etc. — the British names, I am sorry to say, were very few.

But I have set forth the scheme in full elsewhere,¹ and must not do it again. My own proposals may be nonsense: but if the great men of the world would accept

¹ *A Better Sky* (Methuen), 1944.

the principle, it should not be difficult to reach agreement – international agreement – at all events for the sixty-four main ‘navigational’ stars.

Our own astronomers, certainly, are not hot in opposition. I boldly sent my suggestions to the Royal Astronomical Society, and received the following nice reply:

The President of the Society yesterday brought your letter of the 25 October, together with the enclosed article and chart ‘A Better Sky’, before the Council. The chart was examined with great interest, and your whole suggestion of changing the nomenclature of the stars was received with appreciation. At the same time it was felt that as far as Astronomy was concerned the adoption of such a change would require international agreement, which is clearly impracticable at the present time.

And, since we were still at war, I could hardly quarrel with that.

There was also an invitation to dine and discuss, which I gratefully accepted. It was, for me, a memorable meal. We met at some restaurant in Soho, at a long, narrow table set diagonally across the room, I suppose to represent the Ecliptic. There were about thirty astronomers, and one other guest in naval uniform, Vice-Admiral Sir John Edgell, K.B.E., C.B., F.R.S., the Admiralty Hydrographer. I had the honour to sit next to the President, the great Eddington. Opposite to him was the Astronomer Royal, Sir Harold Spencer Jones. Across the table, on my star-board bow, was Sir James Jeans. The astronomer on my right, as we sat down, made a very surprising remark. Looking round the company, most of whom were well advanced in years, he said: ‘We generally have a Quiet End – and a Noisy End. Tonight, I rather feel, we’re at the Noisy End.’ I had visions of the astronomers pelting each other with tomatoes or singing rude songs: but they behaved very well.

You can imagine with what trepidation this amateur person rose to address that eminent audience about the stars. But I harangued them for twenty minutes. Sir James Jeans then rose up and went out without a word. After a short speech from the Hydrographer of the Navy, we had a general discussion, which, I thought, was surprisingly friendly. There was no cry of ‘Hands off Our Sky!’ Indeed, I concluded that astronomers do not much care what names we give to the stars. For in their official work they do not use names but the Greek-letter labels. ‘Betelgeuse’ is α Orionis, and ‘Benetnasch’ is η Ursae Majoris, so ‘Nelson’ or ‘Milton’

would suit them just as well – though to change the names of constellations would be another thing.

Encouraged by the evening, I wrote to Sir James Jeans and asked if he would write an introduction to *A Better Sky*, which was asking for trouble, no doubt. Sir James took the view that there was quite enough international ill-feeling already, and seemed to think that my proposals might start another war. Major Walter Elliot, M.P., nobly did the job instead.

The most favourable review of the book – and I have no shame in rubbing this in – was written by the Astronomer Royal in the *Sunday Times*. He said, rightly:

He is fighting for a principle, not for his particular naming or grouping. . . . Every reader will be tempted to try his hand at improving the scheme: he will find it entertaining and instructive, and in the attempt he will learn a great deal about the stars and the constellations. And perhaps eventually a better sky will be the outcome.

So there!

I should like to add that I am not the first wild fellow to play this game. The Venerable Bede began it. He wanted to name the Signs of the Zodiac after the eleven Apostles and St John the Baptist. Why not? We could start that way as well as any other: and the Apostles are surely more suitable to the sky than the Ram, the Scorpion, and the rest of the pagan zoo.

There, then, I leave the torch for some younger runner to carry along. And I must remark once more that all the trouble was directly due to the dear old lady who gave me that wretched sextant.

I always took my sextant with me on liner trips, and the captain and navigating officer were always very kind to me. At the end of a voyage to Buenos Aires in the *Highland Brigade* the Captain presented me with a model of the ancient Back Staff which he had got the ship's carpenter to make. It was inscribed A. P. HERBERT NAVIGATOR. This is one of my proudest possessions.

All this boasting is to show that in the second section of this book, where I trespass into the navigator's world, I do so with proper respect and at least a half-pint of knowledge and experience.

Then, some years ago, a young officer from H.M.S. *Dryad*, the navigational establishment, told me that they were looking for more rapid and less laborious methods. Three years ago I invented a sort of 'sextant' which requires no 'horizon',

no information, no sums, and, except perhaps for 'parallax', no corrections: and a 'universal' Sun Clock which, again without sums, claims to find the latitude and longitude at any hour of the day, anywhere.

A kindly officer from the Admiralty came to see me and I have a letter from him saying that both are 100 per cent sound in theory: no one, however, has rushed forward to test the possibility of practice. I have not the resources to make a proper instrument, with verniers and so on, but I think that somebody should.

About my height-finder, for example, the officer wrote: 'I was very interested in your "poor man's sextant" and have no doubt that the theory is correct. It would not, to be frank, have any naval application, I think, since, although the Government tries to avoid over-paying us, they are always willing to provide us with a sextant when we want one.'

Yes, sir, but not a sextant which requires no 'horizon', which would operate on a misty day when the ship is in a sunny island surrounded by mist - or in a clearing in a jungle where the Marines have landed, and are lost. This, for example, would have done as well as the normal sextant in that Labrador cove, and, if I had had it then, I should have been spared a great many calculations.

I had to let these things go then and returned to my literary labours. In 1963, to the detriment of the said labours, I returned to the fray, and, I think, made some valuable advances. With my original 'equatorial' Sun Clock I had to establish the latitude before I could get the longitude, and this had to be done rather slowly by trial and error. With my new model, a small circle, six inches wide and six inches high (it would go into one of those cubical cigar-boxes), I claim that I can get my latitude and longitude, doing no sums, in two minutes, or less, before breakfast. This model I call 'Cascanio' - which means Compass and Sextant Clock and Navigator in One. Oh yes, by the way, I find the South without the aid of a compass.

I had better say now that in this book whenever I say that I 'get' the altitude, latitude, longitude, or anything else, I mean (a) that I 'get' it as nearly as can be expected with instruments constructed with dubious materials by a not infallible carpenter, and (b) that with properly constructed instruments I should hope to 'get' it with much more accuracy.

If a man in a bar said to you: 'I bet you I can make a stationary shadow, a shadow that will stay on the same line for three or four hours, sometimes more,'

you would probably lay him generous odds; for all men know that the Sun is always moving, and therefore the shadow he causes must always be in motion too. Save your money if he says it again. I have discovered three or four Stationary Shadows - and useful shadows too. One of them predicts or records for about four hours the noon altitude of the Sun (see pages 167, 178).

The ordinary citizen is not much interested in the altitude of the Sun, though he complains in Autumn when the Sun deserts his garden. He seldom knows his latitude or longitude. He has not the slightest notion of the true significance of the common expression Greenwich Mean Time (this is because nobody tells him - I may be wrong, but I have never met a young person who remembered being told about this at school). But if you lead him to a sundial he will look with interest and a proper kind of awe, recognizing that for once he is seeing Nature, not the Machine, at work. If it was easily readable, and reasonably right, he would look at it again. Two to one, it is not. So he inclines to the unfair opinion beautifully expressed by Hilaire Belloc in one of the many couplets he wrote for sundials:

I am a sundial, and I make a botch
Of what is done much better by a watch.

To this ordinary citizen the first part of this book is addressed. My navigational devices may or may not find favour: but they have led me to consider, and to effect, the improvement of the civil or common sundial. Sundials exist everywhere. New ones are still erected, on the walls of country houses, churches and public buildings. All are unsatisfactory, for the reasons which were in the mind of the great Hilaire Belloc.

The sundial is not 'popular' because it has never been really adapted to the needs of the people. The early astronomers and navigators had many ingenious dialling devices, beautiful things too, which you can see in the museums and the learned books. But they seldom fulfilled the main purpose of a time-piece - to tell the right time, visually, to the uninstructed. The sundials they do see, as a rule, are (a) the wrong size and difficult to read, (b) in the wrong place, that little 'horizontal' in the Rose Garden, for example.

These are not new complaints. In 1724 Jey Singh, the Rajah of Jeypore, said that he found the brass 'astronomical instruments untrustworthy from their small size, the want of division into minutes, the shaking of their axles, and the displacement of the centre of their circles, and the shifting of their planes'. So he constructed vast

dials in stone and marble. His great 'equatorial' dial at Delhi which he called 'the prince of sundials' had a 'gnomon' with these dimensions:

	<i>Feet</i>	<i>Inches</i>
Length of hypotenuse	118	5
" " base	104	0
" " perpendicular	56	7 ¹

But even this enormous work would suffer from the same prime defect as the dials our people see today, whether in gardens, or on the walls of country houses, churches or public buildings. They do not tell the spoiled people the 'right' time, that is clock time. To interpret them correctly you must know the longitude and the Equation of Time. This is the difference between Sun Time and Clock Time and in November it is as much as sixteen minutes. Then there is that tiresome Summer Time which for six months puts every ordinary sundial wrong by an hour.

This is quite unnecessary, as I shall show. Any new private sundial can be made adjustable so that it can tell Mean Time, if required: I have two or three which tell both Sun and Clock Time. I hate Summer Time, that clumsy tampering with clocks, but, if you insist, my dials can give Summer Time too.

The fixed public dial is not so easy. But if any new ones are constructed they should, where possible, be made adjustable for Clock Time (see pages 80-86).

It is my aim to make the sundial up to date. I have brought that blessed word 'technology' into the shadow department.

σνιά (Greek) - means 'shadow'. I announce myself a *skiaphilist* and I advocate *skialogy*.

Bring back the shadow. There are innumerable ingenious mottoes for sundials in Mrs Gatty's well-illustrated book. If I were asked to make one I should suggest:

UMBRA PRO SOLE LOQUITUR

(*The Shadow Speaks for the Sun*)

OR

VOX SOLIS UMBRA

The shadow is as much a function of the Sun as light. You may be bathed in

¹ *The Book of Sun-Dials* - Gatty (George Bell, 1889). There is a model in the Victoria and Albert Museum.

sunshine, sunlight all about you. But unless you peer dangerously into the Sun only the shadow will tell you exactly from which direction comes the light. 'Coming events cast their shadows before' is a ridiculous expression. Coming men or animals may do that sometimes (not if they are walking into the Sun). It is *present* events that cast their shadows before. All those fine officers with their sextants may say confidently: 'The Sun is now due South.' But they cannot, with their sextants, draw a line and say: 'That is North and South.' The shadow of a knitting-needle draws a perfect line. The shadow, if properly interpreted, cannot lie. If on my equatorial Sun Clock, well adjusted, he says: 'The Sun is now over Rio de Janeiro, and the Local Time at Hammersmith is 3 p.m.,' it is so.

So we come back to navigation. In the early days of seafaring the dialler and the mariner were partners, for both were interested in Time and Place, which are permanently wedded. Now, as the song says, 'they have drifted apart.' The dialler knows nothing of the navigator's needs, and the sailor little of the dialler's arts. I seek to restore an old alliance. The officers in ocean-going ships still march on to the bridge at noon, though the modern sailor, of course, is getting rather high-minded about the Sun and stars. He has his direction-finding 'beams' and beacons, his radar and his telephones: and he may, one day, I believe, get a fix from a satellite. Then, at vast expense, he can have this inexplicable 'Inertia' system. A naval officer of whom I inquired could not tell me what exactly was 'inert' about it. I gathered only that it has gyroscopes. Well, beams and gyroscopes and all these wonders depend on electricity which, unlike the Sun, for this reason or that may fail. I had the honour to write some verses for a film to commemorate the latest voyage of that great navigator Francis Chichester. I concluded;

Some cry: 'But we can fly! These arts are stale.
Who wants the rude simplicities of Sail?'
Well, why the Horse? Because the day may come
When Man's fine chattering machines are dumb.

(Meaning 'the Bomb', or other large misfortune.)

Then will survive a horse or two, I hope,
A boy with knife, some logs, a little rope.
Then some young Chichester may hoist his main
And sail away to start the world again.

Alongside the Arts of Sail should still be preserved the Arts of the Sun. I hope that in the less affluent ships, at least, their officers will continue to 'shoot the Sun' at noon, whatever the temptation of the satellite or the inertial system.

The humble garden-dialler may contribute after Bomb Day too. Meanwhile – who knows? – he may stumble on something which will add to the common fund of knowledge on the use of that great luminary – as I shyly believe that I have.

Anyway, I assure him, he will have fun. It is not every boy or man, after all, who makes a hobby of the Sun. Nor can anyone dismiss it as trivial or corrupting to be classed with crossword puzzles, or Bingo. You will find yourself in pretty good company. Sir Isaac Newton and Sir Christopher Wren were eager diallers. That 'prodigious young scholar Mr Christopher Wren' became, in 1654, a fellow of All Souls and designed the sundial there. Newton at the age of nine cut a dial with his pen-knife in the south wall of Colsterworth Church. Both of them, as boys, made that most laborious thing, a spot dial on the ceiling, as I attempted to do in middle age.

George Stephenson, the great railway engineer, studied Ferguson's *Astronomy* and with his son Richard (still at school) made a dial to go over their cottage door.

'The fancy of Charles I', says Mrs Gatty, 'for sundials was well known. Holbein, the great artist, was a lover of them too.'

So no boy need be ashamed of such a hobby. It will be good employment for that new carpentering-set he got at Christmas, and for those long evenings when, we hear so often, 'there is nothing to do'. Nor need he feel old-fashioned. If he is one of these youthful Friends of Space he should know something about the 'technology' of the Universe: and in this way he can at least become a familiar of the principal character in the solar system. When, after some failures, perhaps, he has captured and commanded the Sun on his small dial he will understand much better the problems involved in hitting the Moon or Mars. His dial, if it works, will work according to the rules of the great Spherical Triangle (which we try to explain on page 69). But it is with this same Spherical Triangle that these astronomical wizards have plotted the positions and paths of the heavenly bodies to which his heroes propose to make their way. He may be the only practical Space-man in his class at school. Any boy who can casually refer to the Hour Angle, the Sun's Declination, or the Spherical Triangle, who really knows what is meant by Greenwich Mean Time, is bound to impress (though in my day I should have been beaten by the football captain).

In other ways too — though this has not always an irresistible attraction for the young — the Dial is a generous education. Patience, accuracy, curiosity, tenacity, attention to detail, workmanlike care — all these the Dial breeds and insists upon. It may, too, make palatable some studies which to a healthy boy are often repugnant. He will find with astonishment that even the absurd works of Euclid, and all that 'geometry', can be practically useful — that there is some point in knowing something about triangles and circles. At his first reluctant encounter with logarithms or trigonometry a boy may well say: 'What are these tiresome fellows *for*? I am not going to be a scientist or teacher. When shall I ever want to use them?' I hope his teacher tells him: 'This is folly. Whatever you do in life, you will find that logarithms, the wonderful invention of a Scotsman called Napier (1550–1617) will, if you keep them handy, be often helpful.' I am no scientist, but a literary man: but I find logarithms profitable almost every day. In the last few years, campaigning for the authors for a fair deal in the library world, I have had to do thousands of sums which without logarithms (or the slide-rule, which strains the eyes and is not so sure) I should never have begun. If the Lancashire Public Library has 292 librarians (which is 1 to 3940 of the population) and pays them £627 each what will be the cost to the county if it employs librarians in the ratio of 1 : 2500 of the population, and pays them £700? If the Registered Readers of Britain's Public Libraries are 14.5 million, and the 'total issues' are 460,504,592, how many books does each borrow in a year? and if the population is 52,673,000 what proportion of it are 'registered readers'? If one greyhound runs 990 yards in x seconds, and another runs 880 yards in y seconds, which, if they both keep going, is likely to win a race of 1025 yards? If we import 563,159,246 pounds of tea in a year how much per head of population is that? And how much would a tax of a shilling on a pound bring in? By long division and so on I should never attempt such conundrums: but with your despised logarithms, my boy, they come easy.

Any boy can make and mark a sundial by 'trial and error', as I have often done, but in the winter-time sunshine and shadows are too scarce to make a decent job of that. If he has only a nodding acquaintance with trigonometry (like mine) he can draw his angles and hour-points by the formulae I shall give him later. Indeed, if I were a teacher with a sceptical class I should make a sundial for them and show them, at every turn, where and how their repulsive studies came in.

But Daddy, of course, will have to help: and this will be very good for him. For a man in retirement, who is no longer fit for golf or tennis, and has no love for

lengthy walks, this is an ideal occupation. It goes very well with pottering in the garden: and even when there is no more pottering to do, and every dead leaf has been tidied away, he will constantly be drawn out into the cold but healthy air to see if his latest masterpiece or new idea is working well. He will have the pride and pleasure of making something with his hands though he is no artist. He will acquire knowledge every day, and like the artist, never be satisfied, so he will always be itching to make a new one, better. His workshop, like a studio, will be full of old models which he once thought to be the peak of his craft. These he will dismember at last and use their bones in new creations. He will enjoy the private triumphs and disappointments which make the life of the artist continually exciting. The Sun will generally go in when he is especially anxious to show that he is right at noon, and this will seem like a personal slap in the face from Nature. But then, next day perhaps, he is trying a new thing: he has marked a dial, indoors, according to some new formula, perhaps of his own devising. He takes it out and sets it up, as eager as a boy putting his first boat into the water. The Sun goes in at once. He waits: the cloud will pass. It is just on eleven o'clock. Slowly, but suddenly, a shadow appears and marches precisely on to the tiny spot marked 11. This is an intellectual drama much more satisfying than getting the last clue in a crossword puzzle. It is more like hitting the perfect last line for a lyric. It is even grander. For this is no mere earthly pursuit. He has brought God into the garden: he is a collaborator with the Sun. In these days of electronics, computers, lasers, transistors, and satellites, everything is so damn complicated that the ordinary man gives up. Science has flown out of range. But here is something both scientific and simple.

Then, I would restore the shadow to the artist. In the museums, in Mrs Gatty's book, and others, you may see precise instruments which are also beautiful works of art. I do not mean the crude but interesting things on Saxon churches, or even the dignified columns of stone, with many dials round them, like the ones which stood at Seven Dials and Charing Cross. I am thinking more of the works in brass, minutely designed and gloriously engraved. But I want no artist to make mere imitations of these, for they have the defects, already mentioned, as well as the merits of the past. The sundial is no more out of date than the sailing boat, which, thank God, we have the sense to preserve: but like the boat it needs modern attention. So the artist who is drawn this way must study my modest advice on 'modernization'. The sculptor, after all, is well accustomed to work which is useful

as well as beautiful. On the South wall of Chartres Cathedral there is an angle holding a vertical dial. A friend of mine, a ceramic artist, Mrs R. A. Bevan, of Boxted House, Colchester, has done a smaller but better work, I think — a reclining lady with a dial. This kind of thing could well be 'blown up' in stone for country houses and public places. But they must be 'adaptable', with movable faces to show clock time. I see a noble Vertical on the walls of a Town Hall, adorned with the Arms of the City, and so forth. It must be over a balcony, or near a window, so that adjustments can easily be made. I see too some great and splendid 'Equatorial Dials' on the terraces of the country mansions, large enough for the time to be read with ease from the windows. Whenever I suggest such things for public places I am told: 'The young louts and hooligans would ruin it.' I think this very feeble. If the louts are indeed inevitably pernicious there are ways and means. I should put my dial on an island, surrounded by water — with barbed wire in the water.

So far we have considered the shadow only. Later I shall have something to say about the 'spot' dial, where a ray of reflected light throws a 'spot' of light on to a ceiling or vertical surface, and so records the passage of the Sun. This is not a new notion. Some of the old Ring Dials had tiny holes through which the Sun threw a bead of light on to the hour. Mrs Gatty says:

At Paris, and we believe also at Edinburgh and elsewhere, the hour of noon was at one time proclaimed by a cannon, which was fired by the rays of the sun being concentrated on a magnifying glass so placed as to ignite the powder in the touch-hole when the sun reached its meridian height. The gun stood on a platform which was marked as a sundial, and therefore, simultaneously with the explosion, the gnomon cast its shadow on the figure XII. Small sundials made after this pattern are not uncommon.

I never wish to multiply noise: but here is a playful field for British diallers and toy-makers. I suppose that a really ingenious dial might be made to play 'God Save the Queen' as well.

Science is probably too busy with other things: but the amateur might do some useful experiments with rays of light. To one of my 'verticals' I have attached a small mirror which gives the altitude of the day pretty accurately. What is more, from about two hours before noon it seems to me to give the noon altitude. But my marking of the degrees may well be faulty, so about this I cannot be sure.

The shadow too, I feel, deserves more study. Friendly nautical critics have said that for perfect accuracy it is too wide, too woolly at the edges, and so on. This may be true of some of the old-fashioned dials, with thick gnomons of wood or iron. But if your gnomon is a silken thread (as I have sometimes contrived) the shadow is slender and sharp enough and I can tell almost to a second when it hits the hour. Also, must we assume that no improvements of the shadow can be made with modern materials and modern optical skill and science? After all, no human eye can use the natural Sun. It is too bright: and so our ancestors made tiny holes for it, and they used the Back Staff, the whole point of which was that the navigator stood with his back to the Sun. Also, it was – and is – furry at the edges. But our fathers did not give up. For the sextant, the clever opticians devised a whole series of darkened glasses, so that the navigator sees safely in his mirrors a Sun as clean and round as a billiard ball. This medicated Sun, the Navy claim, resting like a bubble of red, white, or green on the horizon, can be accurate to 0'·1 – or one-tenth of a mile. But the Shadow has never had similar attention. I know nothing of optics, but, if the shadow is considered insufficiently accurate, would it, I wonder, be possible to call in the aid of sunlight, which, *ex hypothesi*, is present at the same time? I have made some rough experiments and suggestions myself. The question does not arise unless navigational accuracy is required, so I relate them later. But some more knowing amateur, when he is tired of the shadow, may stumble on some means of converting it, so to speak, to light.

These, then, are some of the reasons why I wish to 'bring back the Dial' – to the humble garden, to the public park or building, to the country house, perhaps to the ship and the aircraft, and certainly to the Sahara.

The purpose of the book is not merely to tell you what is what (except when I think I know), but to promote interest, inquiry, and experiment; and to give you, what I have had, much Fun with the Sun.

No, that is not quite all. Nothing, nowadays, is any good unless it is 'commercial'. An American who was impressed to hear about one of my devices said: 'Yes, but how many will he *sell*?' I think that, if this enterprise is taken up with a will, not I but others will 'sell' a good many. I see here a new industry, a new export. There used to be firms who specialized in making sundials. Mrs Gatty mentioned two of them. I cannot discover any now. There are instrument-makers, of course, who could, but they are busy with other affairs. Today, when Ministers are eager to create new activities and trades, especially in Northern

areas where there are not enough, I offer them an ancient activity made new.

The sundial is only out of date because it was allowed to go out of date. If we had never got beyond the square-sail there would not be all this sailing today. I hope to persuade you that the Sun and the Shadow are by no means out of date, that every sort of sundial can be made 'modern', and thus will revive the old demand. I see, with Government aid, perhaps, certainly with a kind word from the Minister for Science, and another from the Board of Trade, the new firm of *British Modern Sun Clocks and Co Ltd* setting up somewhere in the North. It will employ a few scientific men, but many carpenters, engravers, joiners and metal-workers. It will greatly swell the sale of the materials required, all made in Britain. It will promise the world every sort of shadow instrument, from the schoolboy's 'Horizontal' to the church's 'Declining Vertical', and fine Equatorials for the country house and municipal gardens. It should qualify as an exporter — why not? It will make the common dials for every latitude, and 'universal' Sun Clocks which will serve the two hemispheres without alteration. What about those 'undeveloped' countries of which we hear so much? They all divide and measure the days, as we do: they all have a constant supply of sunshine: but everyone has not, as we have, a watch, TIM, and a radio. In many an 'undeveloped' village a truthful Sun Clock might be welcome. The Company too will have a research department exploring further into shadow secrets than this humble inquirer is equipped to do. In the use of the sky, and the contriving of tools to that end, Britain has long been a leader. Here, maybe, she can start a new hare in the Heavens.

PART ONE

At Home

I

The Stick in the Sand

Charles Lamb said of the charm of sundials: 'Adam could scarce have missed it in Paradise.'

Like all men Adam, we may be sure, had an instinct to divide the day (*dies* – Latin), and the moving shadow cast by the Sun would attract his attention. But it is also certain that he did not make a sundial, not having been instructed in the behaviour of the Heavens.

What could Adam do?

His first thought would be to watch the shadow of a tree. That would be unsatisfactory: at noon, and for a time before and afterward, the shadow would be a vague and meaningless mess. Then he would plant a stick in the sand.

But every schoolboy knows that that is no good,¹ though, like myself, he may find it difficult to explain why.

Many of our early ancestors began by fixing sticks in the sand. The ancient Greeks used to *measure* the shadow. They talk of a six-foot shadow or mark, or a ten-foot shadow, but nobody seems to know exactly what they did. The ancient Egyptians, rather strangely, left no sundials behind. But it is known that they had a shadow measuring instrument; and they had those obelisks (like Cleopatra's Needle) with the shadows from which they measured angles, and the altitude of the Sun. ('We know that at a later time they actually served as lightning conductors.') The agricultural workers used sticks, or palm-rods, in the sand to regulate their hours of labour. But these were not true time-keepers.

The best way to understand it, I think, is to tell yourself that your sundial is a replica of the Earth, using the Sun as the Earth does. Therefore it must not do anything the Earth would not do, or the Sun will not co-operate. The Sun (as the Greeks believed, and we, for convenience, pretend) goes round the Earth from

¹ One important exception is the Elliptical Dial – see page 132.

East to West, once a day. Your little gnomon, though it is only a needle, represents the axis of the Earth, so it must be parallel to the axis of the Earth, pointing that is, to the North, the Pole Star (and so at an angle equal to the latitude). Then the Sun will go *round* it, as it goes round the axis of the Earth; and it will play the same tricks with your sundial as it does all over the Earth. For instance the ever-changing Declination (the distance of the Sun from the Equator, explained later) does not affect the properly constructed sundial, except to shorten or lengthen the shadow. But it may make nonsense of the stick in the sand.

I will not now attempt to explain why. There are other things which should be explained first. Pray take it as a fact. But not from me. The *Encyclopaedia Britannica* (article DIAL) says: 'The style' (shadow-caster) 'must be fixed in the meridian plane, and must make an angle to the horizon equal to the latitude of the place.'

'A learned man' quoted on page 7 of Mrs Gatty's book (*Sun-Dials*) came to the same conclusion; but he gives the wrong reason so I will omit it:

The shadow of a tree or vertical pillar cannot *permanently* indicate the time of day because . . . the gnomon that indicates the time of day must slope to the horizontal plane at an angle equal to the latitude of the place and must also lie due North and South. This may be illustrated by the blunder the Romans made in bringing a Sicilian sun-dial to Rome.

(Poor things! In 263, during the first Punic War, Valerius Messala captured the town of Catania in Sicily and brought home a sundial. Catania's latitude is $37^{\circ} 31'$ and Rome's is $43^{\circ} 13'$, so the dial, says the book, 'told the time inaccurately enough'. I have gone further. The proper angle for 10 o'clock on a horizontal dial at Catania would be $46^{\circ} 31\frac{1}{2}'$. At Rome it would be $49^{\circ} 52'$. A difference of more than 3 degrees: but this means more than 12 minutes; so the description 'inaccurate enough' is accurate enough. Nevertheless, the Romans, bless them, preserved it 'on a pillar near the Rostra' for 99 years till 164 B.C.)

A vertical gnomon [our learned friend continues] may be used to determine not the time of day, but its length and variation of length in terms of equinoctial hours [i.e. hours on the equator or hours here at the 'equinoxes'] and thus the Egyptian obelisk brought to Rome was used though from causes which Pliny

conjectures the inferences which they drew were subsequently found to be erroneous.

(Poor Romans again!)

Mr Sadler (who prepares the Admiralty Nautical Almanac), said, *à propos* of one of my devices:

On finding oneself in the desert, all that is necessary is to set up a stick of known length vertically in the sand, and measure, at intervals of two or three hours, the lengths of the shadows: it is possible to determine latitude and declination, and, if we know the equation of time and G.M.T., to determine longitude as well. *Unfortunately, this involves a large amount of calculations. . . .*

There is one schoolboy at least who is not impressed by the ancient rule. Bob Owendoff won a glowing story in an American magazine with his 'New Way to Find Yourself in the Woods'.

- 1] Stand a straight stick, three or four feet long, in clear level ground. Mark the tip of the shadow cast by the stick with a stone.
- 2] Watch the shadow till the tip moves over the ground. A few minutes is enough. Mark this second shadow point with another stone.
- 3] Draw a straight line passing through both stones. *This line runs east and west.* The first stone is at the west end of the line.
- 4] Draw the shortest line from the base of the stick to the east-west line. This points straight north (in the Northern hemisphere).

'Surprisingly', the paper says, 'Owendoff's shadow-tip bearings are more accurate than a compass's. The error from true north averages 5 degrees, but is less than that near midday and greater in early morning or late afternoon. A compass deviates on an average 12 degrees from true north in the U.S.'

This is about the best that Adam could have done. But the claims are excessive.

On November 8 1964, in London ($51^{\circ} 29' N$) the Sun shone all day. I set up a needle on a piece of squared paper, and marked the shadow-tip every quarter of an hour from 8.52 a.m. to 3.14 p.m. G.M.T. Then I used a ruler and a protractor. The line which resulted would better be described as a generous curve.

- 1] From 8.52 to 9.45 the line was straight enough but it led 21° South of East – nearly East South East.

- 2] Then it turned North a little and till 11.0 I made the angle 19° South of East.
- 3] Apparent Noon - Noon-by-the-Sun - was at 11.44. Half an hour from that, (at 11.13) the line turned due East. This direction it held till 12.15.
- 4] Then it turned North and till 3.14 maintained a steady direction (I have checked this carefully but cannot explain it) of 24° North of East.

So for exactly 1 hour (11.15-12.15) this 'East-West' line was in fact due East and West. For the rest of the time it was an average of 21° off course.

'This crude set-up', says the magazine 'will also tell time.' Will it? Twenty degrees means 1 hour and 20 minutes.

It was November 8, the Sun low, the Declination $16^{\circ} 39'S$. The trick, I fear, can only come off at the Equinox when the Declination is 0. Bob must have been lucky. Certainly the young should try it the next time they are lost in a wood. It will at least give them a general Easterly or Westerly direction.

But I measured the needle and the length of the shadow at Noon-by-the-Sun and trigonometrically ($\tan A$ (the angle) = $\log h$ (height of needle) - $\log s$ (length of shadow)), I got the noon altitude pretty nearly right. So I felt myself one with the ancient Greeks, measuring their shadows, and the ancient Egyptians with their mighty obelisks.

All day, by the way, I had, a few inches away on the same table, three other perpendicular needles which were telling the time perfectly - one Sun Time and two Greenwich Mean Time. These were operating in 'Elliptical' Dials, a trick I have dug out of oblivion and do my best to explain on page 132. There were four needles stuck in similar bits of wood, but with different markings on the wood. One was almost speechless: the others eloquent and exact. It struck me as a wondrous example of the works, not of God alone, but of the ancient astronomers and dial-devisers. The Elliptical Dial is governed by the 'Declination'. If Adam - and Bob Owendoff - had known about (a) the Declination and (b) the Equation of Time, they could have made their sticks in the sand tell the time precisely all day.

So I had better, at once, try to explain these two tricks of the Sun to Adam. They are important not only to the dialler but to all the human race. But few of the human race could tell you about them.

It may help the student who is baffled by the behaviour of the Heavens to think

of one of those clever comedy juggling acts. What is done is wonderful but nothing goes absolutely right. They seem deliberately to drop a billiard ball now and then, to show how remarkable it is that they do not drop more.

In the Heavens nothing is as neat and precise as we would wish. We say that the Earth takes 365 days to go round the Sun which gives us our 'year'. But in cold fact it takes 365 days and 6 hours. So every four years we have that tiresome business of Leap Year, putting four quarter-days together and making an extra day of them.

Then we know that the Earth goes round itself—rotates on its axis—in 24 hours, which gives us night and day. What we say is that the Sun and the Stars make a circuit of the Earth in that time, and so they seem to do. How splendid it would be if Sun and Stars went round at the same pace, so that Sun Time and Star Time were the same! Oh, no, that would be too easy for us. The stars go just a little faster. The sidereal (*sidus*, star—Latin) day is shorter than the solar day by about four minutes. If a star peeps into your bathroom window tonight, by the way, it will be in the same place four minutes earlier tomorrow. The dialler need not bother himself with star time. It is one more example of the golden truth—'There's always a catch in it'.

Our biggest 'catches' are the *Declination* and the *Equation of Time*. How would an archangel have explained them to Adam?

1] *Declination*—I sometimes complain about astronomical terms which, though of venerable antiquity, unnecessarily baffle the student. But there is no great complaint about this term if you understand that it does not mean 'going down' but 'swerving away', 'deviating', 'turning aside', 'departing from'.

Simply, it is the distance the Sun has departed, North or South, from the celestial equator (which is level with the Earth's equator).

We all say that the Sun goes round the Earth, and Adam would certainly have believed it. It is most convenient to maintain that pretence. But let us for a moment concede the true fact, which is that the Earth goes round the Sun, and takes a year to do it (forget, just now, the details, Leap Year, etc.).

But the Earth goes round the Sun with its head on one side. It has a tilt of nearly $23\frac{1}{2}$ degrees. (No book that I have seen has told me why, but there it is.)

If the Earth marched round with its head straight its face would always be full in the Sun—that is, the Sun would always be over the Equator, and we should

not in these islands see so much of it as we do. We should have no Summer, no Winter, but a sort of soggy Autumn all the year.

But through this fortunate tilt the Sun spends half of the year North of the Equator, and half of it South. It is never more than $23\frac{1}{2}$ degrees away.

Now $23\frac{1}{2}$ degrees means 1410 miles. London is 3089 miles from the Equator. So when the Sun is at his top point North of the Equator he is 1410 miles nearer to us — only 1679 miles away.

This happens on June 21. From 8 p.m. on the 20th till 10 p.m. on the 21st the Declination is the same, the top figure, $23^{\circ} 26' 36''$. This, no doubt, is why it is called the summer *Solstice*, meaning, the Sun stands still. It is also our Longest Day. That day in 1964 the Sun rose at 3.40 G.M.T. in Latitude 52° , say Colchester, and set at 8.24 p.m. — nearly 17 hours of Sun. At midnight on June 22 the Declination is $23^{\circ} 26' 30''$. The Sun has begun its long descent, a little lower every day. It reaches the level of the Equator again on September 23. At midnight on that day it is still $0^{\circ} 0' 18''$ North. At 2 a.m. it is $0^{\circ} 1' 42''$ South.

This is the *Autumnal Equinox*, when the Night and the Day are the same length — as near as damn it. The Sun rises at 5.48 a.m. and sets at 5.56 p.m.

For another three months it continues down, and we have our Autumn and early Winter. On December 21 it reaches its farthest South. From 6 in the morning that day, till 8 a.m. on the 22nd, it 'stands' at $23^{\circ} 26' 36''$, the same distance from the Equator as on June 21. This is the Winter Solstice — and the Shortest Day. The Sun rises at 8.6 a.m. and sets at 10 to 4. Australia is beginning her Summer. We have the worst of the Winter before us.

I do not quite know why, for now the Sun is climbing back to us. It reaches the Equator on March 20 — 2 p.m. $0^{\circ} 0' 14''$ South — 5 p.m. $0^{\circ} 1' 48''$ North. This is the *Vernal Equinox* — Night and Day the same again. The Sun rises at 6.3 and sets at 6.13. Spring begins.

Then it climbs on till the glorious peak of June 21.

The Declination has been described by some as 'sky-latitude': but this, I think, would be a misleading term, for your latitude is always the same, but the Declination (except at the two Solstices) is altering every second.

You will find the Declination in the Admiralty, or Reed's, Nautical Almanac for every two hours of the day or night: and, if you wish, by mental arithmetic, you can work it out yourself for any minute of the day. Whitaker's Almanack gives it only for noon every day: but this is enough for most of us.

Pause, for a moment, as I often do, to salute the astronomers and almanac-mongers, who can tell you so precisely what the Sun is doing and where. I have no doubt that they could give you the figures for years ahead.

2] *Equation of Time* – This, for the dialler, the skiaphilist, is the other thing that really matters.

The Earth, we have seen, takes a year to go round the Sun – from West to East. But it does not go round in a nice neat circle. Its course is an ellipse, which is a circle someone has trodden on. The trodden part in the middle is nearer to the centre – the Sun – than the ends of the ellipse. When the Earth is at the nearer points it travels faster: when it is at the *shallow* ends, so to speak, it goes slower. Therefore the Sun is not a perfect time-keeper. He was good enough for the ancients who were not in such a hurry. But Man wanted something regular and punctual and, probably in the thirteenth century, constructed a clock.

But we still stuck to the Sun: we had to, for the Sun governs the Earth. Every Briton is properly proud of Greenwich Mean Time but few have the slightest idea what it means. 'Mean' means average. A Mean Solar Day is the average of all the True Solar Days throughout a large number of years. (What wizards made these calculations, and when? I have not been able to discover: but in 1880 Greenwich Mean Time was made legal time by Act of Parliament.)

The astronomers and navigators have even invented a 'Mean Sun', 'an imaginary body which is assumed to move in the celestial equator at a uniform speed round the Earth, and to complete one revolution in the time taken by the True Sun to complete one revolution in the Ecliptic' (that is the path of the Sun which we described under 'Declination').

This does not matter much to the ordinary man or even to the dialler: but he should take note that the units of time he is using all day, his hours, his minutes, and seconds are '*mean solar units*'.

So the Clock and the Sun agree exactly for a few seconds on four days only – April 15, June 14, September 1, and December 25. (Another 'catch' here, you see. You might well expect these four days to be the four important days we have mentioned above, the two Equinoxes and the two Solstices. They are not, though in December it is a near thing. Why is this? I have no idea.)

Sometimes the Sun is ahead, and sometimes he is behind the Clock. The difference between the two is called *the Equation of Time*. It is never more than 16

minutes and 24 seconds. On November 2 the Sun is 16 minutes and 24 seconds fast.

It is given for every day in Reed's Nautical Almanac in this way:

<i>Equation of Time</i>		
Add to Mean Time		
Nov.	oh	12h
1	+ 16 22	+ 16 23
2	+ 16 23	+ 16 24

Whitaker's Almanack gives it also.

The biggest difference in the summer months is on July 25 when the Sun is 6 minutes and 25 seconds *slow*.

On that day, then, if you are peering at the sundial on the church wall, you are the kind of man who knows about the Equation of Time, and the shadow says 11.55 you will say: 'Ha! the Sun is *slow*. That means 1 minute past 12. The *Rose and Crown* is open.'

The dialler must always know the Equation of Time.

There is another way of thinking, and talking, of the Equation of Time, which has some merit.

Professor Chapman, an Australian, says in his *Astronomy for Surveyors*:

The *Equation of Time* is counted positive when the mean time exceeds the apparent (or sun) time, and negative when the apparent is greater than the mean. It is thus always the amount that must be added to the apparent to obtain the mean time. Thus we have:

$$\text{Mean Time} = \text{Apparent Time} + \text{Equation of Time}$$

or
$$\text{Clock Time} = \text{Sundial Time} + \text{Equation of Time}$$

The equation of time is thus positive if the sun is 'after the clock' or the true sun transits after the mean sun.

Now let us go back to our stick in the sand.

The properly constructed sundial, with its style pointing to the Pole and representing the Earth's axis, is not bothered by the changes of Declination. What it does today it will do this day fortnight - which is to record the Apparent or Sun Time at its site.

But the stick in the sand cannot cope with the declination, because it is not

imitating the Earth, and therefore cannot expect the Sun to play. It has no authority. It does not point to the Pole but to the Zenith, a point in the firmament immediately above you. Stick up a needle at the base of the gnomon of your horizontal dial and compare the two shadows. At Noon they will be together. At other times, at different times of the year, they may agree: but on the whole the needle will be quite untrustworthy.

BUT there is at least one notable exception which really does 'prove' (or rather test) the rule. In the Elliptical Dial (see page 132) the surface is flat, or 'horizontal', and the needle, or gnomon, is perpendicular. So it is a kind of stick in the sand. But there is this important difference. In the elliptical dial the gnomon must be 'set to the declination'. That is, if the declination is 10° South, you plant your needle in the 'minor axis', the meridian line, 10° South of the major axis – the East-West line: and it tells the time faithfully. This is my own idea (it is not mentioned by any of my books) but it seems to show that it is the changes of declination, and nothing else, which make the stick in the sand mendacious. If Adam or Bob Owendoff had known about the Elliptical Dial they would have done much better.

The conclusion is, then: 'Learn the rules – and put not your trust in Sticks in the Sand.'

II

Dial Dictionary

Or, Don't let the language alarm you

Now, before we go into action on the making of particular dials, I had better explain some of the queer language we may have to use later on. Writers on such affairs, like some doctors and lawyers, have a tendency to assume that we all know as much as they do. I wish to avoid that error.

Then, the astronomers and navigators, rightly grateful to those that went before, and engaged in one of the most truly international crafts of all, have clung, I sometimes think too long, to old expressions which make these affairs unnecessarily obscure to the student – Azimuth, Right Ascension, Analemmatic, and so on. But the words sound well enough, and it is often difficult to think of anything better. The thing is not to be frightened by them. Often the most pompous word turns out to mean something extremely simple.

This chapter is not compulsory reading for every dialler now; much of it should be skipped by the beginner: but he may wish to come back to it for this or that.

Adjustable is, I think, a word of my own. It is applied to a sundial which can be adjusted, adapted, or manœuvred so that it tells Mean Time, or even Summer Time, and so overcomes the admitted disadvantages of the old-fashioned simple sundial which tells Sun Time only.

Altitude, means, especially for our purposes, the altitude of the Sun. Reed's Almanac says: 'The Observed Altitude is the angular height of an object above the visible horizon, measured on a Vertical Circle (which is a Great Circle perpendicular to the horizon) by a sextant. After correcting this Observed Altitude for Dip, Refraction, Parallax and Semi-Diameter . . . the true Altitude is obtained.' (But note later on that the Herbert 'Sextant' – or Height-Finder – does not require

all this correction. Parallax, perhaps, sometimes needs attention but I am not sure about that.)

A useful tip – if you want to know what the Sun's altitude will be, or was, or should have been, at Noon-by-the-Sun,

a] add the Declination (if North) to the Co-Latitude.

b] subtract the Declination (if South) from the Co-Latitude.

(This Co-Latitude, also called the complement to the Latitude, is 90° minus the Latitude. The Co-Latitude of Lat. 50° is 40° .)

$$\begin{array}{r} \text{London is Lat.} \quad 51^\circ 30' \text{N} \\ \quad \quad \quad 90 \quad 0 \\ \hline \quad \quad \quad 38 \quad 30 \end{array}$$

Thus on June 21 at Noon:

$$\begin{array}{r} \text{Co-Latitude} \quad 38^\circ 30' 0'' \\ + \text{Declination} \quad 23 \quad 26 \quad 36 \text{N} \\ \hline \text{Sun's Altitude} \quad 61 \quad 56 \quad 36 \end{array}$$

This is the highest the Sun reaches in London.

On Christmas Day it is:

$$\begin{array}{r} \text{Co-Latitude} \quad 38^\circ 30' 0'' \\ \text{minus Declination} \quad 23 \quad 23 \quad 30 \text{S} \\ \hline \text{Altitude} \quad 15 \quad 6 \quad 30 \end{array}$$

Apparent. This appears to me to be what they call 'redundant'. *Reed's* – 'The *Apparent Sun* is the real and actually visible Sun of which observation can be taken.' *Apparent Noon* 'is the time at which the *Apparent Sun* is on the Meridian of a place'. *Apparent Solar Time* at any place is simply the measurement of the True (or actual) Sun's distance from the meridian of the place – reckoned Westward.

In other words the *Apparent Sun* means the Sun.

Apparent Noon means Noon-by-the-Sun.

Apparent Time means Sun Time, as opposed to Clock Time.

I propose to use the simpler terms. The point of *Apparent Sun* is to distinguish

it from an imaginary body called the Mean Sun. But that does not make apparent necessary. Why not 'the Sun' and 'the Mean Sun'?

Arc is 'a part of the circumference of a circle'. But every arc is opposite to an angle at the centre, and is described in degrees. So they speak of measurement in degrees as measurements in 'units of arc' or simply 'in arc'. Time and Arc are the Heavenly Twins who work as one for the navigator and the dialler. The Sun covers 15° in 1 hour: so the longitude of Tenerife can be expressed either as 15° West or 1 hour West. This is perfectly summed up by the expression 'Hour Angle'. That is the distance of the Sun measured Westward, either in 'units of Time' (hours and minutes) or 'units of Arc' (degrees). If the Sun is over Tenerife his Greenwich Hour Angle is 15° or 1 hour. If your ship is then in 15° East longitude the Local Hour Angle is 30° or 2 hours.

The first part of the long sums they used to do to discover their longitude was all in terms of degrees. The prime object was to work out the 'hour angle', and after miles of logarithms this was at last announced — in degrees. That was at once converted into Time and compared with Greenwich Time. The difference between them gave them the longitude, in Time, which was converted back into degrees.

Ship's Mean Time	14	10	0
Greenwich Mean Time	12	10	0
	<hr/>		
Longitude	2	0	0
	= $30^\circ 0' 0''$		

'Longitude East Greenwich Time least'. So their longitude is 30° East.

The ordinary dialler will not want to find his longitude (unless he goes on and makes a Herbert Sun Clock): but he will often be wanting to turn Time and Arc into each other. This is easily done if he has a Reed's Nautical Almanac. On page 212 (of the 1964 edition) is a 'Table for Converting Arc into Time — and Vice-Versa'. After a little he will be able to do most of what he wants in his head.

There are 360 degrees in every well-conducted circle and 24 hours in every day — 24 goes into 360 15 times so 1 hour = 15 degrees.

There are 60 minutes in an hour — 15 goes into 60 4 times — so 4 minutes = 1 degree, so 20 minutes = 5 degrees. And so on.

There are some rules laid down in the Admiralty Manual of Navigation (Vol. II), e.g. *Arc Into Time*: Multiply by 4 and divide by 60.

I find it quicker to look up Reed's.

All this is beautifully devised, and I have but one complaint. The wizards have got 'minutes and seconds' of Arc as well as Time. In every degree there are 60 'minutes' marked with one tick - ': and in every 'minute' there are 60 'seconds', marked with 2 ticks - ". My Latitude then is $51^{\circ} 29' 26''$.

15 minutes (of Arc) = 1 minute (of Time)

I call this unnecessarily confusing: but there it is.

Azimuth is a nice old Arab word, but a good example of confusion, and means: 'The arc of the horizon between the elevated Pole (the Pole above the observer's horizon) and a vertical circle through the centre of the object.' But as Reed's Almanac tartly remarks: 'It simply means the *bearing* (or compass direction) of a Heavenly Body calculated from the North or South points of the horizon.'

No sailor would say: 'The *azimuth* of the *Bismarck* is 85° East.' I see no point (there may be one) in using such language about a star.

Compass. If you are compelled to use this instrument you must find out what is the 'magnetic variation' or you will be bogged in error. This mysterious and tiresome aberration varies all over the world, and even from place to place in the same country. Suppose you are told that the magnetic variation is 10° West. This means that you must turn the compass till the needle rests on 10° West. It is then pointing to the Magnetic Pole. But to set your sundial you want *True* North, and this is indicated by the N on the compass.

Reed's Nautical Almanac (1964) reproduces the Admiralty Magnetic Variation Chart 1960. This shows the variation as about $8^{\circ} 0'$ West in the Solent, $9\frac{1}{2}^{\circ}$ West at Falmouth and 7° West in the Thames Estuary. It is decreasing slowly - by $6'.5$ annually.

A small compass is useful for giving you the general direction, and for checking your observations, but must not be trusted too much.

Culmination is a word I have only seen in Reed's Almanac, but I like it. It is 'the time of a Heavenly body reaching its highest altitude when it crosses the observer's meridian or "culminates" '.

'Culmen' is a Latin word, a contracted form of *columen*, meaning, 'the point, top, summit'. 'Culminate' goes back to the seventeenth century. Milton used it:

All Sun-shine, as when his Beams at Noon
Culminate from the Aequator.

Declination (see page 39).

Degrees (see 'Arc').

'E' (see 'Marking').

Earth, Motions of. You may see, in other books, some confusing statements concerning the motions of the Earth — or the Apparent Sun, by which, as a rule, they mean the same thing. For though it is established that the Earth goes round the Sun we have agreed to pretend that the Sun goes round the Earth.

I do not say that these statements are wrong; but I should like to make a shy attempt to reconcile and explain them.

The Earth, as I understand the arrangements, does two things:

a] it goes round itself, that is, it rotates on its own axis, which stretches from Pole to Pole, once a day, and thus causes day and night. It rotates *uniformly* from West to East. ' . . . the uniform rotation of the Earth which results in the apparent and equally uniform rotation of the celestial sphere, so that heavenly bodies are continually crossing and returning to an observer's meridian, gives rise to the unit known as day' (Admiralty Manual of Navigation, Vol. II, page 95).

b] it goes round the Sun in an elliptical orbit, from West to East, in a year, or in 365 days 6 hours (hence Leap Year). But this action is *not* uniform. The Admiralty Manual of Navigation, Vol. II, page 96, says:

The apparent solar day is not an interval of fixed length because the Earth does not move along its orbit round the Sun at a constant speed. *The speed is greatest when it is nearest the Sun, and least when it is farthest away.* The distance it travels along its orbit in any fixed interval is therefore variable. The time taken for it to make one complete revolution of 360° on its axis gives such a fixed interval, but that interval will not be the length of a day as defined by the Sun.

Very well. We think we understand that, do we not? The Earth, and therefore the Sun, proceeds irregularly, and so is an untrustworthy measurer of time – or anything else.

But then I recall the words of 'a learned friend' quoted on page 6 of Mrs Gatty's book – *Sun-dials* – who evidently knew a lot: '*The Sun's motion in his diurnal track is uniform: he always describes the same angle in the same time.*' I can support that from my own modest experience. In my Equatorial Dials (to which we shall come) all the hour-divisions are equal, and if they are drawn accurately the shadow passes from one hour-point to another in exactly 60 minutes.

But the Equatorial Dial, like the others, is bothered by the Equation of Time, and has to be corrected, like the others, accordingly, to obtain Mean Time.

What, then, of the 'irregular' motion of the Earth of which we hear so much? Can it be that (except perhaps for the Admiralty Manual) our pastors and masters have not sufficiently distinguished between the two motions of the Earth. As I see it,

a) the uniform *rotation* of the Earth does cause the Sun to travel uniformly and tell the time uniformly during the *day* (15 degrees – 1 hour): but

b) the irregular *revolution* over the *year* does add up to the major irregularities which caused us to invent the clock.

If this is right, I can only say that I never saw it so clearly explained before.

Ecliptic is the path of the Sun which I described in my shy words about Declination. Reed's, more grandly, says: 'It is the Great Circle on the Celestial Sphere in which the Sun appears to move during its annual movement round the Earth. Its plane is inclined $23^{\circ} 27'$ (which is the Sun's maximum declination) to the plane of the Celestial Equator, which angle is called the Obliquity of the Ecliptic.'

But why 'Ecliptic'? As often, my navigation wizards offer no explanation. They simply talk about 'the Ecliptic' as if anyone not certified must know what that means. But the Oxford English Dictionary says: 'So called because eclipses of the moon can happen only when the moon is on or very near this line.' If this is right it seems a very silly name: for the important character here is not the Moon but the Sun. It should be Sun Way, or something of that sort more pompously expressed. How about 'The Obliquity of the Sun'?

Equation of Time (see page 41).

Equator was originally 'Aequator'. It is the imaginary belt round the belly of the Earth, or more elegantly: 'a great circle of the celestial sphere whose plane is perpendicular to the axis of the Earth. When the Sun is on the Equator day and night are equal in length: hence the name' (O.E.D.).

Equinoctial, says Reed's, means 'the Celestial Equator - the Equinoctial is a great Circle dividing the Celestial Sphere into two equal parts. It is in the same plane as the Earth's Equator'.

(By the way, when you read sentences like that, doesn't it make you laugh to think that Latin and Greek are regarded as 'Dead Languages', not worthy of study?)

Equinox (see page 40).

Gnomon is a Greek word (meaning 'inspector, indicator') - and so is *Style*, which means the same thing. It is 'a pillar, rod, or other object which serves to indicate the time of day by casting its shadow on a marked surface: especially the pin or triangular plate used for the purpose in an ordinary sundial' (O.E.D.).

In ancient days the term included a vertical gnomon used for observing the meridian altitude (i.e. at noon) of the Sun. Anaximander of Miletus (560 B.C.) erected such a 'gnomon' at Sparta. It enabled him to observe the equinoxes and the solstices when the shadow would be the same length.

The whole art of dialling was once described as 'gnomonics'.

I prefer myself the word *Style*, which is shorter and easier to say. This may come from the Latin *stilus* (a stake or pole, pointed instrument for writing), or the Greek *στῦλος* (a column, or pillar). Remember St Simon the Stylite, an ascetic who lived on the top of a pillar? The word goes back to the sixteenth century, which is good enough for me.

Horizon (Greek origin again, by the way) officially is 'Where the Sea and Sky apparently meet' (Reed's). Unless he has a clear horizon, sharp and unsullied by mist or cloud, the navigator cannot take a sight of the Sun with a sextant; and he has to hurry at twilight, when he is 'shooting' the stars, for fear of losing his horizon.

But this is a somewhat inadequate definition. As we all know, you can have

things 'horizontal' a long way from the sea. 'Horizontal' sundials exist all over the country. Once again the Oxford English Dictionary does better: 'Parallel to the plane of the horizon: at right angles to the vertical line: level, flat: measured in a line or plane parallel to the horizon.'

Hour Angle has been mentioned briefly under 'Arc'. The Hour Angle of the Sun is the distance it has travelled Westwards from you (measured in Time or Arc) on its daily round. More officially, it is 'the angle at the Pole between the observer's meridian and the meridian through the Sun'. At 1 p.m. when the Sun has been going Westwards for an hour since noon the Hour Angle is 1 hour or 15 degrees. At 10 o'clock in the morning tomorrow it will be 22 hours or 330°. At noon, when it is over your meridian and has completed its round, the Hour Angle is 24 hours, or 0°, for now it starts again.

The Greenwich Hour Angle is 'the angle at the Pole between the Meridian at Greenwich and the Meridian through the Sun'. The Local Hour Angle is his distance from you, if you are not at Greenwich.

Hour-Points, Hour-Lines, Hour-Divisions. The purpose of a sundial is to enable you to say, when the shadow falls on a particular point: 'It is now 9 o'clock - or 20 minutes past eleven, or five minutes to 1.' These are the Points, etc., referred to here. But I fear this definition may lead me into a dissertation.

As the sundial is a kind of clock you might well suppose that, as in a clock, the hour-divisions would be equal, and that, as is the case with clocks, and watches, each dial would be like another. Oh no! here is another catch coming: but again, let it not alarm you. It adds to the fun. Difficulties overcome are about the greatest fun there is.

You have probably noticed when you peered at that horrid little 'Horizontal' in the rose garden, that the 'hours' were all of different sizes. The hour from 6 to 7 in the morning, is often twice the width of the hour from 11 to 12 or 12 to 1. If you peer up at that nobler 'Vertical' on the wall of a church you will see the same thing. But not quite the same: for though the Vertical's hour-divisions are also irregular they are not quite the same as the Horizontal's. Later, when we come to the 'Equatorial' Dial we shall see that all the hour-divisions are equal, as in a clock.

You may well ask 'Why?' You will be surprised by some of the answers you

get. Even experts stammer and hedge if you ask them suddenly: 'Why is 6-7 on a horizontal dial so much larger than 11-12?' One expert said at first: 'Isn't it because the Sun moves faster in the early morning? Or perhaps it's the shadow. In the morning hours the Sun is rising *vertically*. Between 11 and 12 the movement is nearly horizontal. But I'm not sure. I'll look it up - and ring you.' And, bless him, he did.

Meanwhile, it occurred to me that the Miscellaneity of the Hour-Divisions (why shouldn't I invent a pompous expression?) could not be explained by the Sun moving faster or slower at this or that time of day. For you could have - I did have - on the same table a Horizontal, a Vertical, and an Equatorial Dial, all three marked differently, but all correctly telling Time-by-the-Sun. It is the same Sun, at the same time: it cannot surely go fast on one dial and, at the same time, slow on another. It must be the shadow which varies its rate of progress.

My friend duly rang me up and said: 'Have you seen the cylinder?' 'Yes,' I said. I was going to add that I hadn't quite understood it: but he said: 'Well, that's it. Good luck!' and rang off.

I studied 'the cylinder' again (in Mrs Gatty's book). This is an imaginary transparent cylinder, on which the Sun is shining from the left. It has itself a tilt like the tilt of the Earth, $23\frac{1}{2}^{\circ}$ to starboard, the right. Inside it are:

a] near the top, a circular surface level (or parallel? I think level) with the Equator: and

b] at the bottom a circular surface which is 'horizontal' - level with the horizon.

The top circle (a) is divided into 24 equal divisions of 15° - that is, 24 equal 'hours'. Dear little dotted lines are then drawn from the hour-points down the barrel of the cylinder to the horizontal circle at the bottom. At the end of the dotted lines quite differently angled hour-divisions appear from those on the 'equatorial' circle. Don't ask me why, for Heaven's sake. But there, evidently, the answer is. The marking of the hours on any dial is not governed by the velocity of the Sun but by the angle at which the rays of the Sun strike the dial's surface. When the dial is level with the Equator it strikes the surface at the same angle all day: and so the hour-divisions are equal and uniform. If the dial is any way cock-eyed - that is, away from the level of the Equator, - then the hour-divisions will be cock-eyed and irregular; and each cock-eyed dial will have its own set of hour-lines, according to its cock-eyedness. So the Horizontal has one set of angles and hour-divisions, and the Vertical another.

(Having got away with this, I hope, and not wishing to throw you into confusion again, I must confess, in parenthesis, that one stage in the argument has me groping still; see 'Earth, Motions of'.)

But how, you may well say now, if every dial is differently marked, how am I to know how to mark it? I refer you to 'Another Part of the Chapter', as Shakespeare might have put it – 'Marking'.

Latitude. 'Latitudo' (Latin) meant 'breadth or width', and the lines of latitude do go round the belly of the Earth, and other points, sideways. But in fact it is measured upwards and downwards. The Latitude is 'the angular distance of a place on the Earth's surface North or South of the Equator'.

The Latitude of Greenwich is $51^{\circ} 28' 38''$ North.

Every degree has 60 'minutes' and every 'minute' of latitude is said to be one nautical mile – 2026 yards.¹ Every minute has 60 'seconds', so every 'second' means $33\frac{1}{3}$ yards (but nobody bothers much about the 'seconds').

Greenwich then is 3089 nautical (3556 land) miles from the Equator.

Longitude. The lines (or meridians) of longitude go vertically up and down the globe, and the atlas: but in fact they are measurements of width, East and West. It is, 'the angular distance between the Greenwich Meridian and the meridians passing through any place, measured along the Equator, and named East or West of Greenwich from 0° to 180° '.

A degree of longitude has 60 'minutes', like a degree of latitude. But here is a catch. A 'minute' of longitude does not mean a mile except on the Equator. As you go North to the Pole the Earth narrows and the degrees of longitude get smaller.

You will find in Reed's (page 331) a table showing 'Length of a Degree of Longitude in Various Latitudes'. In Latitude 45° a degree is 42.55 miles wide. In Latitude 55° N it is 34.53 miles. In Latitude 60° it is only 30.11 miles, so a minute is only half a mile. In London a 'minute' is about 1200 yards.

The Longitude of Greenwich is 0° (see 'Prime Meridian').

Marking means merely the marking on your dial of the Hour-Points, the half-hour and quarter-points, and, if you are near enough, and your dial is large enough, 5 and even 2 or 1 minute points. How?

¹ But there is a catch here – see 'Mile'.

1] Our earlier ancestors used to do this by drawing elaborate geometrical figures, like an X-ray picture of the human abdomen. These are intimidating, and not, I think, necessary for you and me.

2] Later wizards have done it with trigonometrical formulae, which, if you can draw angles accurately, is the best. As we saw under 'Hour-Points' each breed of sundial has a different set of hour-divisions, so there are different formulae for each. For convenience, I will give all the formulae I know together here. They give you the angles which you must draw *at the base of your style or gnomon*, the point where the shadow begins, to establish your hour-points.

In all the formulae

H means the angle for the HOUR you require, 1, 2, 5, etc.

h means the hour angle of the Sun at any particular moment. You allow 15° for each hour - 30° for 2, 45° for 3, 75° for 7.0 (a.m.) or 5.0 (p.m.) and so on.

L means your Latitude

a] *Horizontal Dial* $\log \tan H = \log \tan h + \log \sin L$.

I want the hour-line for 11 and 1 in Latitude 51° 30'. I get out my NORIE'S or BURTON'S Tables ('Logs, Sines, Cosines, etc.').

$$\begin{array}{rcl} \log \tan 15^\circ & (h) & 9.42805 \\ + \log \sin 51^\circ 30' & (L) & 9.89354 \\ \hline \log \tan H & & = 9.32159 = 11^\circ 50' \end{array}$$

(I got this formula from the *Everyman Encyclopaedia*. It is also given in Chapman's *Astronomy for Surveyors*.)

An encyclopaedia of 1820 (for glimpses of which I am indebted to the National Maritime Museum at Greenwich) says:

To describe an horizontal DIAL trigonometrically - In large dials where the utmost accuracy is required geometrical lines are best set aside: and in lieu thereof the lines of the dial are to be determined by trigonometrical calculation. M. Clapiès in the *Memoires de l'Academie Royal des Sciences*, anno 1707, has done the world good service in this respect; having rendered the calculation of the hour-

lines, which before had been operose enough, exceedingly easy and expeditious. . . . And first, for an horizontal dial. As the whole sine or radius is to the sine of the elevation of the pole of the place [i.e. the Latitude] so is the tangent of the sun's distance from the meridian for the hour required to the tangent of the angle required.

Which, I think, more wordily, comes to the same thing.

b) *Vertical Dial*. In my innocence I used to think that the same angles would do for a Vertical. But, of course, as we shall see, the angle made by the style with the face of the dial is the angle not of the Latitude but the *Co-Latitude* (90° minus Latitude). With this important amendment the formula is the same.

$$\begin{array}{rcl} \text{Log tan } H & = & \text{log tan } h + \text{log sin Co-Latitude} \\ \text{log tan } 15^\circ & & 9.42805 \\ + \text{log sin } 38^\circ 30' & & 9.79415 \\ \hline \text{log tan } H & = & 9.22220 = 9^\circ 28' \end{array}$$

Mr Chapman gives a different formula, but it comes to the same thing.

$$\begin{array}{rcl} \text{Log tan } H & = & \text{log cos Latitude} + \text{log tan } h \\ \text{log tan } 15^\circ & & 9.42805 \\ \text{log cos } 51^\circ 30' & & 9.79415 \\ \hline & & 9.22220 = 9^\circ 28' \end{array}$$

Which only shows how wonderful trigonometry is.

c) *Elliptical Dial*. The sage of 1820 gives no formula for this obscure Dial. But I am proud to say that, by a fluke, I think I have discovered one, of which you will hear more later (page 135).

$$\text{Log tan } H = \text{log tan } h - \text{log sin Lat.}$$

d) *Equatorial Dial*. The angle for 11 and 1 is 15° from the meridian line, for 10 and 2, 30° , and so on - every hour-division is 15 degrees wide.

To save trouble for any reader who lives also in Latitude $51^{\circ} 30'$ here are all the angles for that Latitude (London):

	<i>Horizontal</i>	<i>Vertical</i>	<i>Elliptical</i>	<i>Equatorial</i>
11 and 1	$11^{\circ} 50'$	$9^{\circ} 28'$	$18^{\circ} 54'$	15°
10 and 2	$24^{\circ} 19'$	$19^{\circ} 46'$	$36^{\circ} 25'$	30°
9 and 3	$38^{\circ} 3'$	$31^{\circ} 54'$	$51^{\circ} 57'$	45°
8 and 4	$53^{\circ} 35'$	$47^{\circ} 9'$	$65^{\circ} 43'$	60°
7 and 5	$71^{\circ} 6'$	$66^{\circ} 4'$	$78^{\circ} 10'$	75°
6	90°	90°	90°	90°

Formula: $\log \tan H =$	$\log \tan H =$	$\log \tan H =$	$H = h$
$\log \tan h +$	$\log \tan h +$	$\log \tan h -$	
$\log \tan L$	$\log \sin$	$\log \sin \text{ Lat.}$	
	Co-Lat.		

This will show you if it is still necessary that the variations cannot have anything to do with the Sun's (or Earth's) velocity. For the same Sun may be shining on the four dials at once. When the dial is level with the Equator the Sun strikes it at the same angle at every hour, so the hours are equal.

(I am not *quite* sure about that last sentence. But shall we leave it?)

Now if you have a fixed sundial (not, that is, a Herbert Adjustable) and you use the formulae set out above, your dial will tell the time correctly, but it will be Local Sun Time only. To get Greenwich Time you will have to make mental allowances for (a) the Equation of Time and (b) Longitude. You may not have Norie's or Burton's Tables (but you should): you may fear and despise trigonometry. Very well. You prefer to rely on Fact, and so you may. I did myself for a long time.

3] *Trial and Error.* There remains what I may call (for why should we not be pompous too?) Pragmatical Description - or Trial and Error. One great advantage of this is that, within limits, you can eliminate that difference of longitude.

First, then, you make sure the meridian line of your dial lies true North and South. Thereafter, when you can, and when the Sun shines, you dart out and mark the hours, halves and quarters as the shadow falls upon them.

But how will you know when exactly to make your mark? You have marked 12 already (page 61) relying on your 'Orientation'. When will you mark 1?

That mark - 1 - will mean that it is then 1-by-the-Sun. But to find out when

that is you will have to consult the clock – or, better still, TIM on the telephone. (This will cost you 3d. but at certain times you can get ‘the pips’ for nothing from the B.B.C.)

If you are wise, as I assume, you did this already at noon. You did the sum the navigators do at sea before they take their noon-day ‘sights’. They will ‘shoot the Sun’ with their sextants at Noon-by-the Sun, when the Sun is due South. But they want to find out at what time by the clock it will be Noon-by-the-Sun. So do you.

They have invented a convenient quantity called ‘E’ (rather out of fashion now, but I find it better than the latest thing – the Greenwich Hour Angle). ‘E’ is 12 hours *plus or minus* the Equation of Time.

Today, shall we say, is July 17. You are on the meridian of Greenwich. You consult your Almanac (the Admiralty – Reed’s – or Whitaker’s) and you see that the Equation of Time is *minus* 6 minutes and 4 seconds. (*Minus* means that it is to be subtracted from Mean Time. The Sun is *slow* on the clock.)

$$\begin{array}{r}
 \text{h} \quad \text{m} \quad \text{s} \\
 12 \quad 0 \quad 0 \\
 - \quad 0 \quad 6 \quad 4 \\
 \hline
 \text{'E'} \quad 11 \quad 53 \quad 56
 \end{array}$$

So that is ‘E’. The rule is,

$$\text{Hour Angle} - \text{'E'} = \text{Ship's (or Local) Mean Time}$$

At 12 noon the Sun has finished his daily round, so the Hour Angle is 0° or 24 hours.

$$\begin{array}{r}
 \text{h} \quad \text{m} \quad \text{s} \\
 \text{Hour Angle} \quad 24 \quad 0 \quad 0 \\
 - \text{'E'} \quad \quad 11 \quad 53 \quad 56 \\
 \hline
 \text{S.M.T.} \quad \quad 12 \quad 6 \quad 4
 \end{array}$$

That, then, 12 hours 6 minutes and 4 seconds (or rather 1 hour because of Beastly Summer Time) was the moment by the clock when you marked 12-by-the-Sun on your dial. You need not do the sum again when it moves to 1 p.m. (or 2 B.S.T.). The Equation of Time, you will see in the Almanac, is increasing, but

very slowly. At midnight it was *minus* 6 minutes and 1 second. At midnight tonight it will be minus 6 minutes and 6 seconds. In the next 12 hours it will increase 2 seconds only. So perhaps at 6 o'clock this evening (if you are still at it and are very precise) you should make your marking a second later — at 6 hours 6 minutes and 5 seconds. But you need not bother during the afternoon.

Now 12. 6. 4. is *Local Mean Time*: and wherever you are you can get *Local Mean Time* in the same way. But since you are on the Meridian of Greenwich it is also *Greenwich Mean Time*. That is, to get *Greenwich Time* — the 1 o'clock news, say — you must add 6 minutes to what your dial says.

But suppose you are not on the meridian of Greenwich. Suppose you are in Longitude 1° East — near Colchester. One degree, as you will see on page 212 of Reed's Almanac, means 4 minutes. That is, the Sun, coming from the East, passes over you 4 minutes before it passes over Greenwich. At noon, then, you will have to do as the sailors do. To get their longitude they compare Ship's Mean Time with Greenwich Mean Time, which they have on the chronometer — or get from the radio. And to get the Greenwich Mean Time of Noon-by-the-Sun you must allow for the longitude. When you do that you must remember the immortal poem:

Longitude West, Greenwich Time best
Longitude East, Greenwich Time least.

So at noon you will finish the sum thus:

	h	m	s
Hour Angle	24	0	0
— 'E'	11	53	56
Local Mean Time	12	6	4
Long. East		4	0
Greenwich Time	12	2	4

(We subtract 4 minutes because Greenwich Time is 'least' — If you were in 1° Longitude West it would be 12. 10. 4.)

At 12. 2. 4 then by the radio you will mark 12 noon on your dial on 17 July in Longitude 1° East.

You need not do the long sum every time. Make some 'quick' rules of your own, thus:

1] My longitude is $14'$ – or 56 seconds – West. So when I want to turn Sun Time into Greenwich Mean Time I must always add it (Longitude West, Greenwich Time best). But I try to think of this as *minus* 56 seconds – meaning that in my longitude my Sun Time is always 56 seconds *behind* Big Ben.

So if the Equation of Time is *minus* too – say *minus* 1 minute and 4 seconds – I add the two together making 2 minutes.

	h	m	s	
	12	0	0	Long. – 0 56 seconds behind G.M.T.
	–	1	4	E.T. – 1 4 minutes „ „
'E'	11	58	56	Shadow 2 0 „ behind G.M.T.
H.A.	24	0	0	
L.M.T.	12	1	4	
Long. W			56	
G.M.T.	12	2	0	

If the Equation of Time is *plus* the Sun is *ahead* of the clock, but my longitude makes him still 56 seconds *behind* so I must take the difference – 1 m. 4 sec. minus 56 sec. = 8 seconds.

2] If I live near Colchester – Long. 1° – or 4 minutes – East my shadow is permanently ahead of Big Ben (Longitude East, Greenwich Time least).

	h	m	s	
	12	0	0	Long. + 4 0 minutes ahead of G.M.T.
E.T.	+	2	0	E.T. + 2 0 „ „ „ „
'E'	12	2	0	+ 6 0 „ „ „ „
H.A.	24	0	0	
L.M.T.	11	58	0	
Long. E –		4	0	
G.M.T.	11	54	0	

If the Equation of Time is *minus* 2 minutes (Sun *behind*) I take the difference - 4 minus 2 = 2.

3] What should I do if I lived at Falmouth, which is 5 degrees, or 20 minutes, West of Greenwich?

On that same July 17 at Falmouth the situation at Noon-by-the-Sun is this:

	h	m	s
H.A.	24	0	0
'E'	11	53	56
L.M.T.	12	6	4
Long. W		20	0
G.M.T.	12	26	4

The normal fixed dial is 26 minutes behind the Town Clock and the B.B.C. My answer is I should *not* have a normal fixed dial at Falmouth. If you insist, you could play the same trick and embody the longitude, but it would be much more difficult. Far better have (a) an adjustable Horizontal or (b) a Herbert Equatorial Sun Clock, which takes care of the Equation of Time, Longitude, Summer Time and all. To these we shall come.

Resist the temptation, when marking your first dials, to draw firm, confident lines from the gnomon to the hour-point. They give an elegant fan-like effect - but they may be wrong, and it is a great bore to have to rub them out. Draw the hour-points only first, lightly, in pencil.

Meridian. In Latin *meridianum* meant 'the South', and *meridianum tempus* 'noon'. Then *tempus* was left out and it meant noon by itself.

It is a nice word but we have made a proper muddle of it. We keep the old idea and talk about taking 'the meridian altitude' which is done at *noon* when the Sun is due *South*. Then we made it 'An imaginary Great Circle extending from North to South Pole. Any heavenly body reaching the highest point of its arc is said to be "on the meridian" of any observer.'

But now it is 'over the meridian'. We have transferred the Great Circle to the Earth, and those lines of longitude you see on the map are called by many 'meridians', whether it is noon there or not.

This does not greatly matter: but you may as well know. The meridian of Greenwich (whether celestial or terrestrial) is 0 (see 'Prime Meridian').

Mile. The mile sounds simple but is pretty complicated. There are three miles:

1] The length of a 'minute' of arc measured along the equator is constant and is known as the *geographical mile*. It is 6087·2 feet – or 2029 yards.

2] The nautical or 'sea' mile is, strictly, the length of a 'minute' of arc measured along a meridian. But owing to the curve of the Earth, this length varies, it seems, from about 6046 feet at the Equator to about 6108 feet at the Pole. This was unsatisfactory for practical purposes, so the Admiralty took an average and fixed the Standard Nautical Mile at 6080 feet and 2026 yards.

3] The land or 'statute' mile is 1760 yards. This was in part a legacy from the Romans whose mile was reckoned to have been about 1618 yards. Our agricultural measures, founded on farmers' habits, came in too. Queen Elizabeth decreed that the mile should be 8 furlongs, or 40 perches of $16\frac{1}{2}$ feet, 5280 feet, or 1760 yards. And it was so. The 'statute' mile is never used at sea, or on charts.

Orientation. Our fathers, rightly, made a great fuss about 'orientation' – the setting of a sundial due North and South: and they had toilsome methods which seem to me to be quite unnecessary. Some sundials, properly constructed, can be self-orienting – or, I prefer to say, self-southing – without the aid of a compass. One must have a compass about for confirmation and checking: but the kind of small compass which finds its way into the ordinary home is often very unsatisfactory. It has been carried in the pocket, perhaps, and banged about a bit. It does not answer quickly to a change of direction, and often the needle lies down in the wrong place as if it were tired. Also, as you know, the compass is wrong. The needle does not point to the 'true' but the 'magnetic' North. The error may be East or West, it may be 10 degrees or 20 – at the moment in England, I believe, it is 8 degrees West (see 'Compass'). The sailors question the accuracy of my instruments, but when their own great instrument is 10 degrees out it is cheerfully called 'the magnetic variation'. They know that it is wrong, and how to deal with the error: also they have in big ships the gyroscopic compass which eliminates it. But few householders have a gyroscopic compass, know what the magnetic variation is or what to do about it. So I have been seeking simple methods of doing without the compass.

Here are the learned directions of J. Wigham Richardson at the end of Gatty's *Sun-Dials*:

I recommend the following procedure in fixing a horizontal dial.

First consult a large Ordnance map (scale of an acre to a square inch) and place your dial approximately due North and South. Then level it by means of a spirit level. Correct the line of the gnomon both by a compass and the sun at noon, as rectified for the equation of time.

Then at the distance of some four or five yards north of the dial drive two long poles into the ground with a cross-piece at the top, like a tall Greek letter *II*. The like, not so tall, to the south of the dial.

Hang both north and south plummet lines, and during the day make the two lines and the gnomon in one line.

Ask any astronomical friend, or any ship's captain, at what hour the pole star crosses the meridian, at that hour get the two plummet lines in a line with the pole star. Be careful in doing this to move the one as much to the right as the other to the left, for otherwise the gnomon will not be in the same line.

Having got the plummet lines true to the pole star, it will not be difficult in the morning to adjust the gnomon.

This procedure is, I am sure, effective, but it is the kind of thing that got the sundial a bad name. It is too much like work. By the way, it may surprise you to learn that, like the compass, the famous North Star is not always a reliable guide. Indeed, like other stars, it goes round and round and can be as much as a degree East or West of North. But if you follow Mr Richardson's methods, do not waste your time hunting 'astronomical friends or ship's captains'. Buy Reed's Nautical Almanac. This excellent work records for the first day of every month the time of 'transit' (meridian passage) of all the stars, including Polaris, and there is a Correction Table which will tell you the time on any day of the month. But are such exertions necessary?

The writers of the article in the *Encyclopaedia Britannica* (DIAL and DIALLING) do without the Pole Star:

... The exact determination of the meridian plane which passes through the point where the style is fixed to the surface is not so simple.

The position of the XII o'clock line is the most important to determine accurately since all the others are usually made to depend on this one. We

cannot trace it correctly on the dial until the style has been itself *accurately fixed in its proper place*. When that is done the XII o'clock line will be found by the intersection of the dial surface with the vertical plane which contains the style; and the most simple way of drawing it on the dial will be by suspending a plummet from some point of the style whence it may hang freely, and waiting until the shadows of both style and plummet-line coincide on the dial.

Yes, but you can do that any time of the day by turning the back-side of the dial towards the sun. The act must be done at the exact time of apparent noon (see page 57), and then it is convincing. Also – the writer too easily skates over this – the style *must be accurately fixed in its proper place*. How?

That great fellow Mr Francis Chichester, who knows much more about these affairs than I do, has devised an ingenious *Sun Compass* which he has published with an explaining booklet (George Allen & Unwin – 5s.). This is one answer to the question 'How?'

Mr Chichester claims that his compass is accurate enough to test the compass of an aircraft. Certainly it should do for the preliminary setting of a garden sundial. Thereafter, at Noon-by-the-Sun, the plummet trick will give the final answer.

You must know your longitude, and get the Local Mean Time. Then by an ingenious graticule you find the bearing of the Sun. You turn the thing over and there is a compass rose. You turn the bearing you have found towards the Sun and your compass is set. I recommend this little instrument.¹

But there are some other tricks, especially for the garden dialler who does not want to do elaborate 'orientation' exercises every time he shifts an instrument. There is, for example:

The 'Runner on the Style'. For short, I will call this the Bobble. This is a small object, the smaller the better, which is fixed on the style but can be moved up or down at will, a bead or a bit of rubber with a hole in it, a small ring with a screw thread fitting a thread on the style, a thin bit of wood stuck under and across the style, and so on.

On the Equatorial Dial and Sun Clock the Bobble does splendid service. If (a) the Latitude is known and (b) you set the Bobble on a graduated style at the declination figure of the day, the shadow of the Bobble will travel round the rim of the dial all day. That is, if you pick up your dial and put it somewhere else you

¹ Francis Chichester, 9 St James's Place, S.W.1.

orient it at once without consulting a compass, by seeing that the Bobble shadow is touching the rim as it did before.

Thus the time-shadow and the declination work in harness together. The same sort of thing, I feel, should be possible with the Horizontal and Vertical dials - but I confess myself frustated. Here the shadow of the Bobble does not go round the dial (that is a peculiar magic of the Equatorial), but it behaves in an orderly and predictable fashion. If there is no declination it will pass across the dial in a straight line at right angles to the meridian line. Otherwise, during the middle hours of the day, it may seem to be clinging to a line, especially if the declination is small, but in fact it is following a curve. So far, this does not seem to lead me anywhere. But again, could not the expert draw me a declination curve or two? Then I could fix a bobble so that its shadow fell on this curve or that, and if the Housewife moved it she would have to replace it somewhere so that the shadow still fell on the curve. Or not? I hoist the V-flag: 'I require assistance'.

LATER - Captain Mark Taylor R.N. saw my signal and nobly responded. Here is his formula for drawing the declination lines on a vertical (it is too late, alas, to give you a diagram). I cannot pretend to understand the whole why of it, but I can assure you it works - and it is not as alarming as it looks.

Let B be the base of your style. D is the point where a declination curve crosses an hour-line. The object of the exercise is to find, for each hour-line, the distance of D from B .

L . = Latitude ($51^{\circ} 30' N$). Dec. = Declination $15^{\circ} 40' S$ on February 6 1966.
 h = hour angle, e.g. 30° at 10 or 2 o'clock.

You must also have PH - the height of a perpendicular dropped from the tip of your style, or if more convenient, a bobble, to the dial (length of style 5.5 inches $\times \cos Lat.$). I make this 3.42 inches.

Let us tackle the hour (H) of 10 or 2. There are three stages.

1] First, for each hour, we work out an angle C which is the angle between the style and the hour-line, and:

$$\begin{array}{rcl} \text{Tan } C & = & \sec h \times \cot L. \\ \log \sec 30^{\circ} & & 10.06247 \\ \log \cot 51^{\circ} 30' & & 9.90061 \\ \hline \text{tan } C & & 9.96308 \\ C & = & 42^{\circ} 34' \end{array}$$

2] If both the Latitude and the Declination are North – or South – ('same name' as the navigators say) you *add* the Declination to *C*. If they are different you subtract it.

$$\begin{array}{rcl} C & = & 42^{\circ} 34' \\ - \text{Dec. } S & = & 15^{\circ} 40' \\ \hline & & 26^{\circ} 54' \end{array}$$

Let us call that *K*, for fun.

3] Now the drill is:

$$B \text{ to } D = \sec K \times \cos \text{Dec.} \times \sec L. \times PH$$

and you do a fourfold adding act:

$$\begin{array}{rcl} \log \sec K & = & 10.04973 \\ \log \cos \text{Dec.} & = & 9.98356 \\ \log \sec L. & = & 10.20585 \\ \log 3.42 \text{ inches} & = & 0.53403 \\ \hline & & 0.77317 = 5.93 \end{array}$$

5.93 inches is the distance, on the 10 and 2 hour-lines, of *D* from *B*.

Magic, is it not? Do the same for the other Hours, join the *D*'s and you have your curve.

For the Horizontal the procedure is the same, with three exceptions:

1] to find *C* –

$$\tan C = \sec h.a. \times \tan \text{Lat.}$$

2] to find *K* –

If Latitude and Declination are 'same names' you *subtract* the Declination from *C*: if they are 'contrary' you *add*

3] in the four-fold addition operation you use *cosec* Latitude instead of *sec*

Formulae for Declination Lines

For a Vertical Sundial

Feb. 22 1966 - 10 a.m.

PH 2 inches

$$1] \begin{array}{rcl} \log \sec HA \ 30 & 0.06247 \\ \log \cot Lat. & 9.90061 \\ \hline \end{array}$$

$$\log \tan C \quad 9.96308$$

$$2] \begin{array}{rcl} C & = & 42^{\circ} 34' \\ \text{minus Dec. } S & 10 & 17 \\ \hline K & 32 & 17 \end{array}$$

$$3] \begin{array}{rcl} \log \sec K & 0.07293 \\ \log \cos Dec. & 9.99297 \\ \log \sec Lat. & 0.20585 \\ \log 2 (PH) & 0.30103 \\ \hline & 0.57278 \end{array}$$

$$BD \quad 3.73$$

For a Horizontal Sundial

Lat. $51^{\circ} 30'$ N Dec. $10^{\circ} 17' \cdot 2$ S

PH 2 inches

$$\begin{array}{rcl} \log \sec HA \ 30 & 0.06247 \\ \log \tan Lat. & 0.09940 \\ \hline \end{array}$$

$$\log \tan C \quad = 0.16187$$

$$\begin{array}{rcl} C & = & 55^{\circ} 26' \\ \text{plus Dec. } S & 10 & 17 \\ \hline & 65 & 43 \end{array}$$

$$\begin{array}{rcl} \log \sec K & 0.38590 \\ \log \cos Dec. & 9.99297 \\ \log \csc Lat. & 0.10646 \\ \log 2 (PH) & 0.30103 \\ \hline & 0.78636 \end{array}$$

$$BD \quad 6.11$$

(BD = distance from declination line, where it crosses Hour line, to base of style.)

But if the Declination was the top figure, $23^{\circ} 26' \cdot 7$ S, on December 22nd, D, I reckon, on the hour-line of 2 or 10, would be 12 inches away from B and your dial may not be big enough. The South Declination curves, on a horizontal, cover much more ground than the North, and have larger intervals between them: and the bigger the declination the more bosomy the curve. So it is a good thing to begin by working out the curve for Declination South 23° South and see where it turns up. The governing factor is the 'Perpendicular Height' of the tip of the style. If the 23° S curve is much too far away, have a Bobble well down the style with a smaller PH. On one of my small six-inch-diameter circles I have got in all the declination curves (that is, every 5°) comfortably. The Perpendicular Height of my Bobble was $\cdot 9$ inches.

I have also made a new Vertical, about 7·5 inches high, and 12 inches wide, with the *PH* of the Bobble 1·6 inches.

All this means long labour – each curve requires a page of calculations. But it is rewarding work, when done. By the Bobble shadow you can actually ‘see’ the Sun approach and cross the Equator, and I like to see it faithfully following its allotted course. It is best to sketch the whole thing out on paper before you mark your dial.

I would also shyly mention the *Herbert Compass* (but only to trigonometrical experts). I thought, one happy summer, that I had made a great discovery:

1] If from a perpendicular surface something, even a needle, emerges, pointing due South, *at the angle of the latitude*, it will, in the early morning, cast a shadow on the angle of the declination;

2] and later, if you add the angle of the declination to the angle of the latitude, the shadow, for some time at least, will lie along the East–West line.

So I constructed the incomplete and erroneous device on plate 1. For one thing, the declination lines should be curved not straight – curving down for North declination, and up, like a nice smile, for South. Captain Taylor did not blow the thing out of the water, as I expected. ‘It is actually’, he said, ‘part of a Vertical South Dial’ and he kindly explained how the curves should be drawn. He used a variation of his formula for the vertical (above) – $\tan L$. instead of $\sec L$. in the fourfold addition sum, and instead of *PH*, the length of my ‘style’ – the emerging needle, or what-not. The curves, he suggests, should be plotted first on a separate piece of paper, and could then be drawn through the same point on the compass, like my straight lines. Or, instead of varying the formula, you could have a style which moved up and down (as in the elliptical) according to the declination – ‘a hole to slip into for each 5° of declination’; and the distances between the holes would be the same as the distances between the lines of declination where they cross the vertical 12 o’clock line.

At this point I felt that the Herbert compass was getting out of Herbert’s range. I leave it to better men to play with. It might be useful (there is no bother with the magnetic variation) and could be a pretty toy.

Two in One. Then there is the trick of having two dials ‘of a different nature’ working together – a horizontal, for example, and an ‘elliptical’ (to which we shall come). These tell the same time at noon, but at no other hour *unless it is the right time*. When they agree, therefore, you may take it that the instrument is

properly oriented. Our fathers, for no good reason, called such a combination an 'Analemmatic Dial' but I reject the term. I call it a Self-southing Double Dial.

Local Mark. This is not perhaps a very 'scientific' suggestion but it is practical. While you are making experiments you do not want to do precise 'orientation' every time you try a new idea or instrument. So, when you are sure where the South lies, choose some local mark, a fairly distant tree or chimney, *not* the holly-hock at the end of the garden, to be your South-point. At Hammersmith, I use a favourite tree across the river.

Plane. This word is frequent in these affairs but nobody bothers to explain it. It comes from *planum* (Latin) - 'a flat surface'.

In Geometry, says the Oxford English Dictionary, it is 'a surface such that every straight line joining any two points on it lies wholly in it, or such that the intersection of two such surfaces is always a straight line'.

So when, as we saw, they say that the Celestial Equator is in the same plane as the Earth's Equator you must imagine two large flat surfaces touching and continuing each other.

Then, some say that the gnomon or style of your sundial must be in the plane of the Earth's axis. This, you may reply, is clearly impossible, according to the definition above. The answer, I think, is this:

The fixed axis about which the Sun and stars revolve is a line through the Earth's centre: but the radius of the Earth is so small, compared with the enormous distance of the Sun, that if we draw a parallel axis (for example, your gnomon) we may safely look on that as being the axis of celestial motion.

Prime Meridian. This is one of the glories of Britain. It is the line, or meridian, of longitude 0° , which passes through Greenwich in South-East London. It also passes through France, and a bit of Spain, and Algeria and the 'Gold Coast': but who cares about that? The great thing is that it passes through Greenwich: and this is no accident.

It was decreed in 1884 by the nations of the world, assembled at Washington, as a compliment to the great work of British astronomers and navigators. All round the world, by sea and air, the navigators are still using Greenwich Mean Time and the Greenwich Hour Angle to establish their positions. It is a good

objection to 'Summer Time' that by altering the clocks we abandon our proud position, and Big Ben booms Greenwich Time no more. Hitler, if he had won, would have decreed that the Prime Meridian should pass through Berlin.

Ending a speech in the House of Commons against the Double Summer Time Bill, 1947, I said: 'Let the Empire go if you must but cling fast to the Prime Meridian.'

Prime Vertical. This is the extraordinary name they give to the East-West line, I cannot imagine why: 'Vertical Circle of the celestial sphere passing through East and West points of the horizon. A heavenly body is on the "Prime Vertical" when it bears East or West (true – not magnetic) – when at right angles to the meridian' (Reed's).

A 'Vertical Circle'? Yes, but the Prime Meridian is just as vertical. Never mind.

Refraction is 'the bending of light from its path that occurs when the ray passes from one medium to another of different density' (Admiralty Manual of Navigation, Vol. III). The sailors, when they get the 'altitude' of the Sun, make a small deduction for refraction, which varies according to the altitude. They, and others, usually assume that refraction also interferes with the shadow of a sundial and affects its accuracy. This, I have always maintained, is wrong; and I think I proved it by my experiments with the Dial of Ahaz (see page 149).

Right Ascension will not disturb the dialler, but he may see it in the books and wonder. It means in effect the sky longitude of a heavenly body. If you happened to be at the First Point of Aries (which is the Greenwich of the sky) and walked along the celestial equator Eastwards for three hours, or 45 degrees, you would see a star called Menkar between you and the North Pole. The Right Ascension of Menkar is three hours.

They also talk of the Right Ascension of the Mean Sun, the imaginary Sun that gives us Mean Time.

'Right', I suppose, means 'straight', not 'right'. The ancients talked of 'right' lines.

The Spherical Triangle. This will not be mentioned except in the navigational Part II. But the garden-dialler, though he may not know it, will be playing with

it all the time, as the man in Molière discovered that, all his life, he had been talking 'prose'.

All problems concerning the position of a ship, or a place, or a heavenly body are solved by the navigator in terms of the Spherical Triangle. This is not quite so alarming as it sounds. It is rather like those little maps which show the different placings of a cricket field - roughly the same, but always a little different.

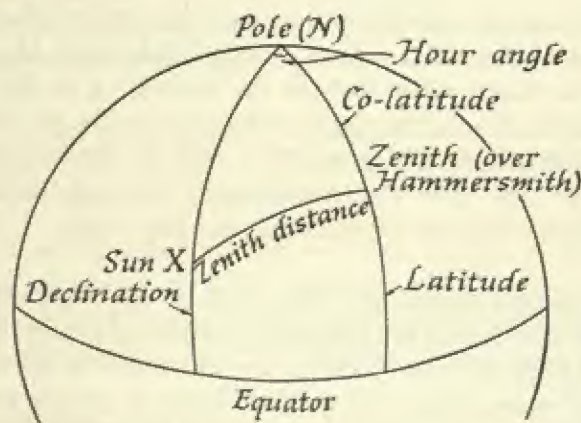
The sides of the Triangle are not lines but curves, and they are measured not in miles but in 'units of arc', that is degrees. The three corners are:

P = the Pole

X = the Heavenly Body

Z = your Zenith (the point immediately above you in the Heavens)

Here is a view of the Spherical Triangle as seen from Hammersmith on a sunny afternoon (*I think*).



The angle at P between PZ and PX is the Hour Angle, which we have met already. When they have found that they have found the Local Time, and by comparing that with Greenwich Time they find their longitude.

PX is 90° minus the Sun's Declination

PZ is 90° minus the Latitude (i.e. $38^\circ 30'$)

ZX is 90° minus the Sun's Altitude - i.e. the Zenith Distance

So putting 2 and 2 together, as it were, they find the Hour Angle. But we won't go

into all that now. One of the claims of the Herbert Sun Clock is that the Spherical Triangle is seen, graphically, in action; and the problems solved without any sums.

Substyle. 'The line on which the style or gnomon stands.'

Summer Time is a mortal foe to the dialler – unless he uses some of the Herbert models. But that is not all there is to be said.

Many Britons suppose that this device is a grand British gift to the civilized world, eagerly accepted by all. In fact, of the 362 'places' listed in the Admiralty Nautical Almanac 1965 only 30 have the asterisk against them which means 'Summer Time may be kept'. Only 8 per cent of the peoples have followed our folly. They are:

Albania, Egypt, Formosa, Hong Kong, Lebanon, Macao, Madagascar, Norway, Pescadores Islands, Poland, Syria, Eire, Morocco, Portugal, Alberta, Azores, British Columbia, Grenada, Iceland, Labrador, Madeira, Manitoba, New Brunswick, Newfoundland, Nova Scotia, Ontario (East), Prince Edward Island, Quebec (East), Saskatchewan (South-Eastern part) and Uruguay.

The rest of the world, if it wants to get up early, gets up early, without tampering with the clocks. So should we. The Government should announce that on the appointed day all government establishments will begin work one hour earlier and express the hope that others will follow suit. They would. The railways might have to alter their time-tables, but in the summer they generally do. If they did not, it would do the lazy nation good to have to subtract an hour: the mariner for years has had to add one when using the tide-tables in Summer Time.

This thing began in 1916. Mr Willett (whose pertinacity at least can be praised) had not made much headway, but in the second year of the war his trick was adopted not to 'save' daylight, or to improve the lot of the people, but to conserve fuel and artificial light. For the same purpose in the Second War, from 1941 to 1945, and again in 1947, we suffered that monstrosity Double Summer Time – 'two hours on'. In 1943 I spent three months in Newfoundland and Labrador on Government duty: the island was governed then by 'British Commissioners', so nearly all official people dutifully adopted it. But the simple fishermen and woodsmen disliked, and largely ignored it. The farther North you went the less it prevailed. Halfway up some would compromise with one hour on: others would have nothing to do with it. In some parts you had to tackle three different 'times'.

'What time do *you* keep?' we asked new friends when they invited us to lunch, and, more than once, we arrived an hour late or an hour early for our appointment.

In 1947, in the 'Double' debates, I tried to get the parent Act repealed, so that the whole institution could be reviewed: but I was out of order. My objections to it are moral, practical, and patriotic. It is a lamentable confession of weakness, I feel, to say that we cannot be persuaded to do what is best for us except by monkeying with a scientific instrument. No instrument should be made to lie, especially not the great Clock of Westminster or the great Bell, Big Ben, which it governs, both famous throughout the world. One might as well 'adjust' the barometer or the thermometer so as to suggest that the weather is better than it is or the patient less feverish than he feels. It is an unnatural interference with the ways and habits of all men, not only farmers and fishermen. Since Man began, his midday rest and refreshment have been governed by the position of the Sun. Now it is irrelevant. The teetotallers have never taken the point but Summer Time drives the citizen to drink at an unnatural hour. Under Double Summer Time, if a publican's opening hour was 11 this became 9 by the Sun, perhaps five hours after sunrise. I think it is a sort of blasphemy too. Time, you may say, is merely a convenience for Man, and already you have tampered with Sun, or God's, Time by turning it into Mean Time. Yes, but Mean Time is respectfully founded on God's Time: the Summer Time Acts defy and deny it. Finally, the British, of all people, should not do this thing. They should be too proud of Greenwich and the place of Greenwich Mean Time in astronomy and navigation to abandon it for a single day (see 'Prime Meridian'). One day it may be proposed that the Prime Meridian shall run through Cape Kennedy: and if we protest, as I hope we should, it may be said: 'But half the year you don't use your dear Greenwich Time yourselves: and there are some who would like to abandon it *all* the year.' How shall we answer that? Methods of telling Summer Time by sundial are considered in this book under 'Adjusting for Clock Time' (page 80) and under the various particular dials discussed.

Sundials

An instrument serving to measure time by means of the shadow of the Sun. . . . It is more accurately defined a draught, or description of certain lines on a plane, or surface of a body given, so contrived as that the shadow of a style, or

ray of the sun passed through a hole therein shall touch certain points at certain hours (Rees Encyclopaedia - 1820).

It must be one of the earliest scientific contrivances. 'Learned men have generally ascribed the invention of it to the Babylonians, from whom the Jews derived it before the time of Ahaz. Herodotus says: "It was from the Babylonians that the Greeks learned concerning the pole, the gnomon and the twelve parts of the day"' (B ii. p. 109).

Ahaz was King of Judah in 741 B.C. twelve years before the foundation of Rome. The Dial of Ahaz, mentioned in Isaiah and the second Book of Kings, is said to have been the earliest dial of which there is any record. If it was the very first, which from its nature is not likely, the sundial would be at least 2700 years old. In a modest way I have tried to revive the Dial of Ahaz, and I claim to have done the 'miracle of Isaiah' (see page 154).

There are many sorts of sundials. In this book you will be troubled with seven only, but it will do no harm to tell you the names of the others. I quote the Sage of 1820 again: 'The diversity of sundials arises from the different situations of the planes and the different figure of the surfaces whereon they are described, whence they become denominated equinoctial, horizontal, vertical, polar, direct, erect, declining, inclining, reclining, cylindrical etc.' He does not mention, here, the elliptical. There have also been hemispherical and even spherical dials, nocturnal and moon dials, ring dials and cross dials, spot dials, and card dials. Then of course there are portable dials and fixed dials.

Principal dials are strictly the Horizontal and the Vertical, but the Sage extends the title to the Polar and the Equinoctial (called by us the Equatorial).

A *Direct* dial faces a cardinal point of the compass, North, South, East or West. A *Declining* dial has to decline or depart from a cardinal point, like so many Verticals you can see on the walls of churches or houses which have carelessly been built not facing due South. The construction of these is a complex business which I examine later - for you might want one on your church or country house. An *Erect* dial is one in which 'the circle whose plane is used, is perpendicular to the horizon' - in other words, an ordinary Vertical (q.v.) drawn on a perpendicular wall, or bit of wood. The full title of this, according to the Sage, is an *Erect, Direct, South Dial*, but we shall be content, I think, with the simple description 'Vertical'.

Reclining Dials and *Proclining* Dials are not *Erect*. One leans backwards – and the other forwards – from the perpendicular. Not much – and I am not clear why. The Rajah of Jeypore, in the eighteenth century, created vast dials, 'of solid masonry and marble', of both kinds. There are models in the Victoria and Albert Museum. But they are, I think, too high for you and me.

Mrs Gatty quotes the amusing plaint of a citizen against the number of sundials in ancient Rome. It is attributed to Plautus, who died about 184 B.C.:

The gods confound the man who first found out
How to distinguish hours – confound him, too,
Who in this place set up a sun-dial,
To cut and hack my days so wretchedly
Into small pieces! When I was a boy,
My belly was my sun-dial – one more sure,
Truer, and more exact than any of them.
The Dial told me when 'twas proper time
To go to dinner, when I had aught to eat;
But, now-a-days, why even when I have,
I can't fall to, unless the sun gives leave.
The town's so full of these confounded dials,
The greatest part of its inhabitants,
Shrunk up with hunger, creep along the street.

(Quoted by Aulus Gellius, B. 3. c. 3.)

Skiaphilist is a word I have invented, meaning shadow-lover (*σκιά*, shadow – Greek, and *φιλέω*, I love – Greek).

Vernier. 'A device, consisting of a short movable scale, by which more minute measurements may be readily obtained from the divisions of the graduated scale of astronomical, surveying, or other mathematical instruments to which it is attached' (O.E.D.).

In other words, you look through the little magnifying glass at the sextant reading of the 'sight' you have just taken. All you can say with your limited powers is that it is 60°, and something more. The vernier enables you to say confidently: 'It is 60 degrees, 27 minutes and 40 seconds'.

Zenith. Your Zenith (Arabic) is the point vertically overhead in the celestial sphere.

If the Altitude of the Sun at any moment is subtracted from 90° what is left is called the 'Zenith Distance' of the sun.

$$\begin{array}{r} \text{Altitude } 50^{\circ} \\ 90 \\ \hline \text{Zenith Distance } 40^{\circ} \end{array}$$

So the sun is $40^{\circ} \times 60$ or 2400 miles away.

The opposite to Zenith is Nadir – but you won't be bothered with that.

III

Particular Dials

There are many sorts of sundials, as we saw on page 73. I shall deal in detail only with a few – especially ‘adjustables’ – which may attract the amateur in modern times, or may be suitable for the country house, the public park or building.

HORIZONTAL SUNDIAL – ADJUSTABLE

Formula for Hour-lines: $\log \tan H = \log \tan h + \log \sin Lat.$

Dial, Horizontal [says Rees Cyclopaedia of 1820] is that described on a horizontal plane or a plane parallel to the horizon.

Since the sun may illuminate an horizontal plane at all times of the year, while he is above the horizon, an horizontal sundial may shew all the hours of the artificial day throughout the year; so that a more perfect dial than this kind cannot be required.

This is true enough. The books often put it first. The modern amateur generally begins with it. It is difficult to say why. For a time-piece which will not tell you the time unless you stand over it is obviously not an ideal type for popular use. But it is simply constructed; and in a way, it is true, it has a particular grace. That sloping solid style, with now and then a curve in the supporting end, attracts the eye as the Vertical's iron bar on the church wall does not.

The style, as you have been told till you could scream, must point to the Pole, at an angle equal to the Latitude, or, as they used to say, the elevation of the Pole. (For learned details see ‘Style’, page 50.)

The surface must be ‘level with the horizon’, or, as you might say, flat.

It must not merely be ‘flat’ but *level*. This is not so easy. In my small garden which slopes almost invisibly down to the River Thames, there is hardly a level square yard. I have to affix little toe-caps to the legs of my table. You must have

a spirit-level and hope for the best. You can buy at Woolworth's (and, I expect, elsewhere) for 2s. 3d., dear little miniature spirit-levels which you may attach with one of those powerful sticky stuffs (Bostik is a wonder) to this or any other portable dial. The professionals sometimes fit a dial with four levelling-screws, which go through the corners of the dial to the ground below. You might try this—it is too much for me.

For marking the hours see 'Hour-lines' and 'Marking' in Chapter II.

The only practical point that remains, I think, is the placing of the style. With the ancients, I gather, the generally done thing was to put the base of the style about one-third of the diameter of the dial away from the south point of the meridian line. In every kind of dial the 6 o'clock line – from 6 a.m. to 6 p.m. – is always at right angles to the meridian line, and points, therefore, due East and West. Putting the style there gave them four extra hours to mark, South of the 6 o'clock line – 4 and 5 in the morning, and 7 and 8 in the evening. But rare must be the amateur dialler who wants to play with dials at those hours. During Summer Time, after all, 6 in the evening becomes 7. Also, the farther down (or up) the dial your style, the smaller will be your hour-divisions. So, myself, I like to put my style on the very edge of my circle. There, then, is my 6 o'clock line – a tangent to the circle, and I have to mark no hours before 6 a.m. or after 6 p.m. But the hours I keep, from 6 to 12 both ways, are wider, and I can make more subtle markings. Here is a point on which all can act according to their pleasure. What must not be forgotten is that the shadow proceeds from the base of the style, wherever it is, and if you are using one of the trigonometrical formulae (see 'Hour-lines') it is from that point that you must measure your angles.

I said that the horizontal dial can only be used by one who looks down upon it. But this can be converted into a merit. Why not a large horizontal on which you look down from your bedroom window in the morning or your study during the day? Such was the very first dial I ever made. It was a circle 6 feet in diameter, and painted green, on some rather rough paving-stones in my garden at Hammer-smith. The style was an iron rod I found lying about. I stuck it in the circumference of the circle, and marked the dial, by trial and error, down to five minutes – including the longitude, as I explain under 'Marking'. I could see the time clearly from two stories up and many a day it told me that my watch was fast, or slow, or had stopped. But gardeners, and mothers, protested that they or their children ran in danger of impalement by the style: so I took it down.

Then, if I were rich, I have often thought, and owned a spacious country estate, somewhere near the main entrance to the house I would build a mighty horizontal sundial for the instruction and pleasure of those who come after. It would be perhaps the Biggest Sundial in Britain. My favourite fancy is a lofty 'gnomon' of clipped yew (or do I mean box?) tenderly maintained at the right angle of the latitude - say 50° in Kent or Sussex.

The clock circle must not be too great, for a long shadow grows wide and woolly as it lengthens. When the Sun's altitude is 60° or more (at the end of June) a pole 60 feet long (the peak of which would be 45 feet above the ground) would throw a shadow 65 feet long (the length of a cricket pitch) on to the figure XII at Noon-by-the-Sun. This would be the shortest shadow of the year. While the yew (or box) was growing I would set up a fine pole to guide the gardener and get the clock into working order. Also it would project beyond the box and give a sharper shadow. The hours would be marked by small round flower-beds, in which the gardener could play pretty tricks - who knows? a special colour for every hour. Between 11 and 12 the distance would be 13 feet - 3 feet 3 inches for every quarter. Between 6 and 7 the distance would be 20 feet - 20 inches for every 5 minutes.

Such a tribute to the Sun, the true source of earthly life, would be fitting, I have often thought, in a municipal garden. But the Committees always tell me that any such addition to the amenities would at once be destroyed by the Lawless and Malignant Young. If this were a serious objection I could plant my gnomon on an island surrounded by a water-lily moat - and I would sink barbed wire among the water-lilies.

Then I made a 'horizontal' on a round table for the pub garden, a green table with the hours painted in white at the circumference. This was a great success. People liked to sit with their beer and watch the shadow approach the end of 'permitted hours'. There were friendly arguments with the landlord when the Sun was behind the clock. 'God's Time is good enough for me' and so on. The right answer to that, of course, is to be found in a statute of 1880 which enacted that the word 'time' in any legal document relating to Great Britain was to be interpreted, unless otherwise specifically stated, as the Mean Time of the Greenwich Meridian.

I commend the Sundial Table to the brewers and those who make their furniture. The style could be flexible, but the markings must fit the latitude or nearly. Most brewers, though, are concentrated in one territory, so this should give little trouble.

Wishing to be more helpful than my predecessors I have worked out the angles for the hour-lines on a horizontal dial for all latitudes. There may, of course, be errors. Notice, in the last column, the varying difference between 6 and 7.

$$\text{Formula: } \log \tan H = \log \tan h + \log \sin \text{Latitude}$$

Angles to be drawn from the base of the gnomon of a horizontal sundial to mark the hours of:

<i>Latitude</i>	<i>11 a.m.</i>	<i>10 a.m.</i>	<i>9 a.m.</i>	<i>8 a.m.</i>	<i>7 a.m.</i>	<i>6 a.m.</i>	<i>Difference</i>
	<i>1 p.m.</i>	<i>2 p.m.</i>	<i>3 p.m.</i>	<i>4 p.m.</i>	<i>5 p.m.</i>	<i>6 p.m.</i>	<i>between 6h and 7h</i>
7°							
(Colombo - 6° 56' N)	1° 52'	4° 1'	7° 0'	11° 54'	24° 25'	90°	
32° (Isaiah)	8° 5'	17° 0'	27° 5'	42° 32'	63° 10'	90°	
42°							
(Rome - 41° 54' N)	10° 9'	21° 7'	33° 47'	49° 12'	68° 10'	90°	21° 50'
45°							
(Bordeaux, Milan)	10° 43'	22° 12'	35° 16'	50° 46'	69° 15'	90°	20° 45'
50°							
(Lizard, Land's End)	11° 36'	23° 51'	37° 27'	52° 59'	70° 43'	90°	19° 17'
51°							
(Taunton - Sussex)	11° 45'	24° 10'	37° 51'	53° 23'	70° 58'	90°	19° 2'
51° 30'							
(London)	11° 50'	24° 19'	38° 2'	53° 35'	71° 6'	90°	18° 54'
52°							
(Banbury - Ipswich)	11° 55'	24° 25'	38° 14'	53° 46'	71° 13'	90°	18° 47'
53°							
(Nottingham)	12° 4'	24° 45'	38° 36'	54° 8'	71° 27'	90°	18° 33'
54°							
(Lancaster - Harrogate)	12° 14'	25° 2'	38° 58'	54° 29'	71° 40'	90°	18° 20'
55°							
(Newcastle)	12° 22'	25° 18'	39° 19'	54° 49'	71° 53'	90°	18° 7'
56°							
(Firth of Forth)	12° 31'	25° 35'	39° 39'	55° 8'	72° 5'	90°	17° 55'
57°							
(Inverness)	12° 39'	25° 50'	39° 59'	55° 27'	72° 17'	90°	17° 43'
58°							
(Sutherland)	12° 48'	26° 5'	40° 18'	55° 45'	72° 28'	90°	17° 32'
59°							
(Orkneys)	12° 56'	26° 10'	40° 36'	56° 2'	72° 38'	90°	17° 22'
60°							
(Hebrides)	13° 4'	27° 38'	40° 53'	56° 18'	72° 48'	90°	17° 12'
70°							
(North Cape)	14° 8'	28° 29'	43° 13'	58° 26'	74° 5'	90°	15° 55'
80°							
(Spitsbergen)	14° 47'	29° 37'	44° 33'	59° 37'	74° 46'	90°	15° 14'

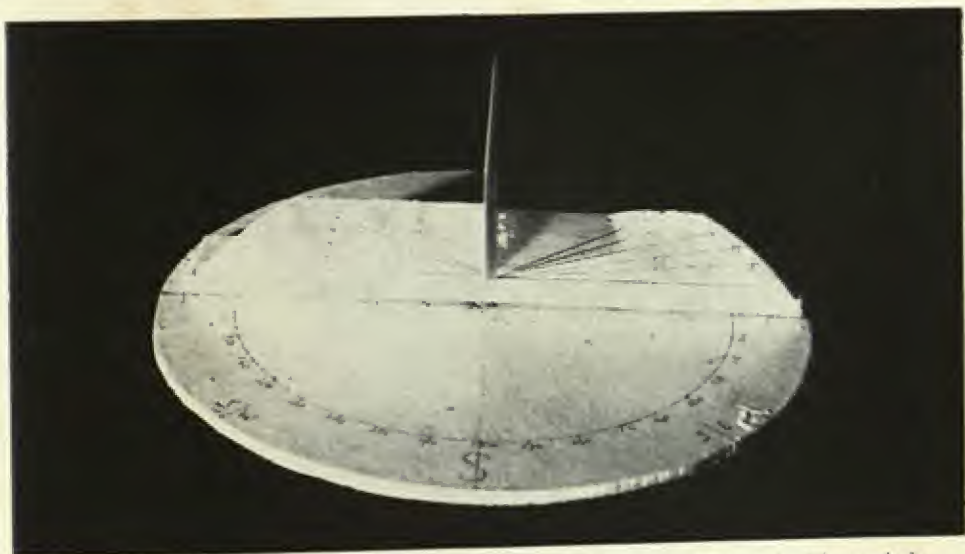
Adjusting for Clock Time

It is not only Nature that makes the Dial differ from the Clock, through the Equation of Time. It is the British Parliament, which first initiated the lie called Summer Time, and has spread it abroad, though not very much. I hate Beastly Summer Time so hotly that I should be happy if my dials told nothing but honest Greenwich Mean Time. I am still capable of adding one hour to a given time, as all the sailors and fishermen have to do when they use the tide-tables in the summer months. But others, I know, have swallowed the mess and like it. So we must do what we can for them.

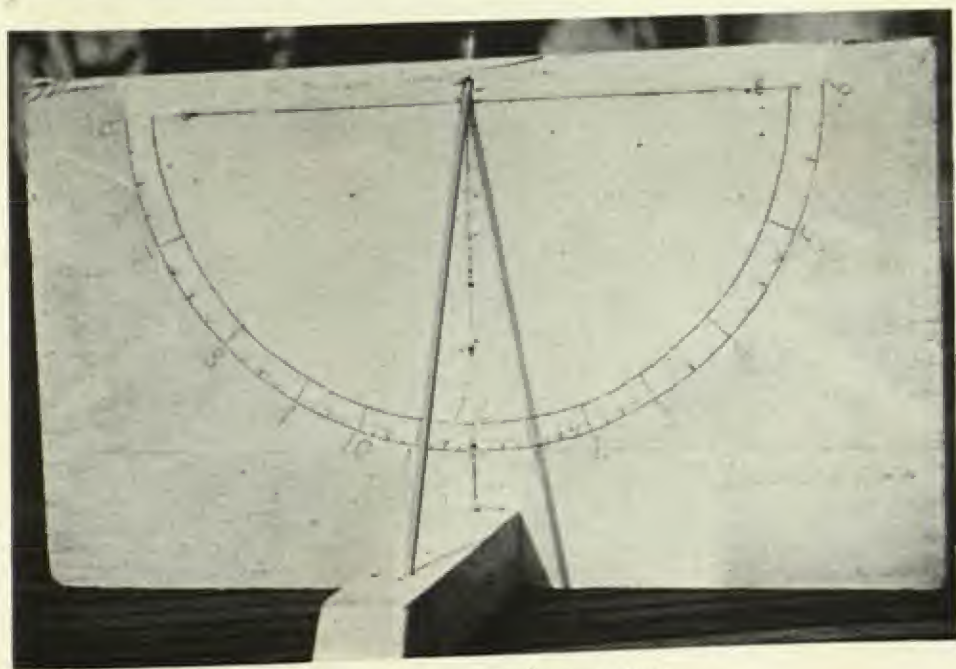
1] *Re-name the Hours.* One simple way, if you have a home-made dial, is to re-number the hours. Paint out your 12 and put 1 instead, and so on. Then you have only to deal with the Equation of Time, which in the period of Summer Time ranges from *minus* 7 minutes at the beginning (March 20) to *plus* 15 at the end (October 24). In the true summer months, May, June, July and August, it is never more than 6 minutes (it is *minus* 6 minutes 25 seconds on July 25).

But in October the Sun still shines and gardening goes on. On October 19 the Equation of Time is *plus* 15 minutes. So even with the hours re-named the housewife is still 15 minutes out. When told by her husband that his dial is telling Sun time only, not clock time, she is inclined to say: 'Then why don't you turn it round till it does tell clock time?' She has something there: but much depends on what she means by 'turn it round'.

2] *The Housewife's Trick.* She probably means 'Why don't you turn the whole thing round?' At first I frowned haughtily on this suggestion. It is against all the rules - your style should always point due North, as we have learned. I considered, and wrote down, other clever objections. 'If, in London, you turn a sundial through 15° - 1 hour - to the West, you are putting it into another longitude, the longitude, nearly, of Berlin. The formula by which you drew your dial does not mention longitude, but the formula was devised on the assumption (a) that the style would be pointing North and (b) that your shadow would be passing over certain areas of your dial at certain speeds. Between 8 and 9, for example, on a Horizontal, the shadow covers $15^{\circ} 32'$, but between 9 and 10 $13^{\circ} 44'$ only (on a Vertical the same figures are $15^{\circ} 15'$ and $12^{\circ} 8'$, a bigger difference). Now by your



1. THE HERBERT COMPASS (a rough idea). Declination 15° South. *Electric light.*



2. THE HOUSEWIFE'S VERTICAL



3. EQUATORIAL DIAL

shift you are trying to make it go from 9 to 10 when the period is really 8 to 9. The Berlin shadow will during that period be passing from 9 to 10, certainly. But the Berlin Sun is not in the same position as the London Sun – it is higher: and a Berlin shadow is not travelling, on a dial, at the same speed as the shadow on a London dial. The Berlin shadow (on a horizontal) is going at the rate of $13^{\circ} 44'$ an hour, but the London shadow is doing $15^{\circ} 32'$ an hour. There must be error.'

But theory is never enough. While patting myself on the back for this reasoning I happened to see some learned words written in 1962 by Dr R d'E. Atkinson, then at the Royal Greenwich Observatory. I thought, mistakenly, that he was saying too what the housewife says, and I made some respectful experiments. They have given some startling results. I have in the last few days (today is April 16) had *two* horizontals merrily doing the Housewife's Trick. That is, they are turned 15° towards the West with their styles, or gnomons, pointing North 15° West, and both are accurately telling Beastly Summer Time all day. One is a small fellow with a three-inch radius, the other is my 'Dial of Ahaz', half-full of water (see page 145). These I have marked with indelible ink and I leave them out rain or shine, day and night. When the rain stops, or the morning comes, there they are, still telling Summer Time, and needing only a small correction in the morning for the new Equation of Time. This is about 0 at this time, and may help a bit. But the big thing is that they are 15° out of their proper alignment. I laugh heartily, I must say, to see the ancient Dial of Ahaz telling British Summer Time. Today I have two Verticals in action as well, doing the same trick perfectly. There does now and then seem to be some of that sagging in the late afternoon that I have noticed in my Adjustables though this may be due to a fault in the instrument or the level. If they do sag at tea-time they can be set again.

A Vertical, by the way, employed in this way, loses an hour of usefulness, for about 5 B.S.T. the Sun and the shadow leave it. The Horizontal continues work as long as the Sun shines.

All this is against my principles and theories – and all the rules. It must be tested by better men with better instruments. But if they confirm the outrageous thing here is a revolution in the dial world, not only for the housewife.

First, it means that if her husband has given her a well-made sundial, horizontal or vertical, with the hour-points appropriate to the latitude, she can say: 'None of your science!' and set her dial by the kitchen clock, to Greenwich Time or

Summer Time, or what she will. There will be limitations, no doubt, according to longitude, the Equation of Time and so on. I am near to the meridian of Greenwich and there are a few seconds only of Equation of Time. Everyone must make his own experiments. But if the trick can take 15° of Summer Time in its stride how much more easily will it deal with Greenwich Mean Time! I got this (with a Vertical) successfully in Spain, when the difference between Sun Time and G.M.T. was 27 minutes. At Falmouth on July 17 it would be 26.

Second, if you have one of those bronze things on a pedestal have a look at it, and see if it cannot be prised off and made mobile - and modern. But if you do this you must be scientific and mark the pedestal. It will be a nice reason for a walk that you must set the sundial. After all, you are not too proud to wind up the grandfather clock.

Third, if the theory stands up, what about new public, country house, or business house Verticals? These are still being constructed.

Why should they not be set out from a South wall on a vertical axis - at the meridian line - so that they can be turned, from a window or balcony, either way, and tell Mean Time, at least, and even, in the right places, Summer Time.

But let not the housewife suppose that all this makes the ancient learning superfluous or vain. We must walk before we run: we must learn all arts thoroughly before we play tricks with them - a truth not sufficiently received by some poets and draughtsmen. If a dial is fixed and immovable it must point to the North, as we have tried to explain: and if you do *not* know the time by the clock your dial must still point to the North, for then only can you get time by the Sun which will give you the rest. The Housewife's Trick comes in when you do know the time, and you can set your dial by the clock; and even then the dial must be correctly fitted to the latitude.

PS. Since I wrote all this I have had an accurate little Horizontal telling Double Summer Time (between clouds - and showers). I thought it was running a little slow by 5 p.m. (Double Summer Time) as I expected. For it was then 3 p.m. G.M.T. and the shadow was travelling at the comparatively low speed of that hour over a fast shadow area on the dial. But it finished strongly like a good conductor and at 6 (Double Summer Time) 4 p.m. (Greenwich Mean Time) it was 'bang on'. A remarkable performance. But too much must not be expected of the 'trick'. I tried it on New York (5 hours slow on Greenwich) and the dial was all at sea very soon.

3] *Herbert Adjustables*. Another method is to turn the *dial* round leaving the style pointing to the North according to the rules. This is what I have been doing for a long time with my 'Adjustables'.

a] The 'Equatorial' Sun Clock (to which we shall come) counters Equation of Time and Longitude, and, if required, tells Summer Time with ease and accuracy – and Sun Time too, with the same shadow.

b] I have made Adjustable Horizontals and Verticals too, but here is a different problem, for the hour-divisions of an Equatorial are equal, but those of a Horizontal or Vertical, as we have seen, are not. My adjustables are certainly good enough for the garden and keep good Greenwich Time most of the day. They shy at Summer Time, and tend, I think, to run fast in the early hours of the morning and slow in the late afternoon hours. It may be that, for reasons which I have explained, this is inevitable. Without an instrument professionally made I cannot be sure. You must make your own and here is the method.

In both dials, the Horizontal and the Vertical, your main, your time-telling dial rests on another, a little larger. The top one is fastened to the lower one at one point only, the base of the style, whatever and wherever it is. Mark both together for Sun Time (the hours on the lower can be marked on a straight cross-line), and 'orient' the instrument. Then swivel the top dial right or left, as the case may be, till the shadow is telling Mean Time. If the Sun is ahead, say 8 minutes, of the Clock, you will put 12 on the movable dial 8 minutes *ahead*, that is, to the right. Then the shadow will fall on the lower 12 at Noon-by-the-Sun; but not on 12 (top storey) till 8 minutes later. If the Sun is six minutes slow you will put 12 (top storey) 6 minutes to the left. Then, when the shadow falls on the meridian line the top dial will show 12.6, mean time.

The housewife will probably do the swivelling simply, but crudely, by reference to the clock. But it is just as well to understand what you are doing: and the house-husband may wish to do the thing scientifically. If so, he must mark on the lower dial in minutes or degrees, or dates, the points to which he will move his 12.

It is remarkable what a big difference can be made (on the Dial) in time by a small movement in space. In the summer months, as I keep saying, the largest Equation of Time is 6 minutes (the Sun is 6 minutes slow on July 17 and August 3). 6 minutes equals $1\frac{1}{2}$ degrees. If you are marking degrees on an Equatorial Dial, where, as we shall see, the hour-divisions are equal, you simply translate Time into Arc – 4 minutes = 1 degree, 16 minutes = 4 degrees, and so on. But in the

Horizontal and Vertical the hour-divisions are not equal. The difference between 12 and 11 or 12 and 1 (when you will probably make your markings) is

$$\begin{array}{rcl} \text{Horizontal} & 11^\circ 50' \\ \text{Vertical} & 9^\circ 28' \end{array}$$

Those intervals each represent 1 hour. So 20 minutes will be represented roughly by $\frac{1}{3}$ of them - i.e. $3^\circ 56'$ and $3^\circ 9'$ respectively. This is the simplest marking to make.

If you want to work out very exactly the marking for, say, 16 minutes (the top Equation of Time - November 3, Sun 16 minutes fast) you must use a formula - with some apprehension I give you my result:

$$(1) \text{ Horizontal } \log \tan H = \log \tan h + \log \sin \text{Latitude}$$

$$\begin{array}{rcl} 16 \text{ minutes} & = & 4^\circ \\ \log \tan h (4^\circ) & = & 8.84464 \\ \log \sin 51^\circ 30' & = & 9.89354 \\ \hline & & 8.73818 = 3^\circ 8' \end{array}$$

$$(2) \text{ Vertical } \log \tan H = \log \tan h + \log \cos \text{Latitude}$$

$$\begin{array}{rcl} \log \tan h (4^\circ) & = & 8.84464 \\ \log \cos 51^\circ 30' & = & 9.79415 \\ \hline \log \tan H & & 8.63879 = 2^\circ 30' \end{array}$$

6 minutes (the highest summer E.T.) will be covered between 12 and 1 on a Vertical by less than a degree ($? 58'$). On a Horizontal it will be $1^\circ 11'$.

At early and later hours there will be a bigger difference between the Sun and the mean markings. 16 minutes, between 12 and 1 on a Vertical means $2^\circ 30'$ - between 3 and 4 $3^\circ 42'$ - between 5 and 6 $5^\circ 56'$. How then, you may ask, does a movement of only $2^\circ 30'$ cater for the later hours?

After endless experiment and calculation I still shrink from a confident answer. An amateur's experiments with home-made instruments may go wrong for so many reasons, faulty orientation, inaccurate marking, bad levels and so on. I have had some completely contradictory results, especially towards the end of the day. In the middle hours, with a small Equation of Time, an error may be

hardly noticeable. I am not satisfied that you will get complete accuracy between 5 and 6 on October and November evenings when the Equation of Time is 10-16 minutes. But then the Sun won't be shining much and the housewife won't be there.

4] On this subject, I must record the learned words of Dr Atkinson. I do not understand them all, but better men will. In the October 1962 number of the *Journal of the Institute of Navigation* he wrote:

If we have a sundial which is correctly computed and set up at some station, and we want it to read the standard time for the zone (after applying the Equation of Time, of course) instead of the local time, we need only to rotate it about the slanting gnomon-edge, through an angle equal to our longitude difference from the standard meridian, it will then be truly parallel to an identical sundial correctly set up on that meridian and will record what that one would. [The Doctor had remarked earlier that 'All sundials everywhere already have their slanting edges parallel since they are all parallel to the Earth's axis']. Quite generally, in fact, if any correctly-computed sundial is *rotated about* its gnomon-edge through any angle θ (degrees), its readings at any given instant will be changed by $\theta/15$ hours, whatever the actual time or date may be. Thus if we construct it with suitable bearings to give this kind of rotation, and if we limit the rotation to two suitable positions 15° apart, we can set it over to the East in spring, so that it will read Summer Time, and can set it back again in the autumn. It is really just like setting a watch. Alternatively, we can provide the rotation with a scale and pointer, and set it day by day (or week by week) so that the dial readings are always corrected for the Equation of Time. The scale can, if we wish, be marked out in terms of the dates when the Equation of Time reaches certain values.

I confess that I was respectfully fogged by some of this. I wrote to Dr Atkinson and asked whether he meant by 'rotating the sundial' rotating the whole instrument (the Housewife's Trick) or rotating the dial and leaving the gnomon pointing North (the Herbert Adjustable). By this time he had left Greenwich and gone to work in Bloomington, Indiana, U.S.A. Some months later he kindly replied from there:

The gnomon must still point *North*, and at an altitude equal to one's latitude (if

one is using a slanting-edge gnomon, and not a ball or a peep hole). The rotation is a rotation of the dial and gnomon *together*, as a single rigid body, about this slanting line, and one will in fact find (assuming that the lines on the dial have been correctly computed in the first place) that a rotation through 15° , measured about this slanting axis, will always shift the shadow-line on the dial by just one hour: one can rotate it through as many hours as one likes, any time of the day, and get a proportional change. If you want it to record Bloomington 'standard apparent time' (6 hours slow on Greenwich apparent) you rotate it 90° about the slanting line: the dial will then slant pretty steeply down to the north, while its intersection with a horizontal plane will be roughly SW-NE, and for a good fraction of each day the sun will shine on the underside, but if you graduate this side too, and prolong the slanting gnomon through it, it will still record Bloomington 'standard apparent' time during the hours when the sun (though risen at Greenwich) has not yet risen (at the latitude of Greenwich) on the 90° W meridian. (Risings and settings are not, of course, correct unless the latitude is suitable as well as the rotation in hour-angle, but the times are correct anyway.) You want a pair of fixed bearings, mounted in the prolongation of the slanting gnomon line, and the whole thing then turns over, so that the normal to the dial describes a small circle on the celestial sphere, passing through a point low in the north, and an elevation $2 \times \phi$, if ϕ is your latitude.

This is evidently not my 'Adjustable' method, or the Housewife's Trick either. It is sound, I am sure, but perhaps too complicated for the common man.

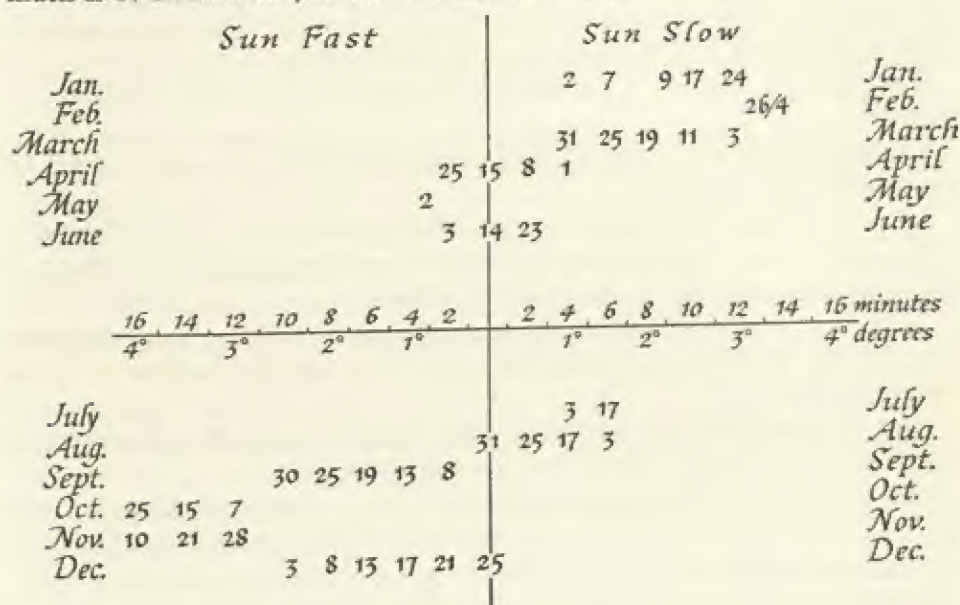
For the ordinary dialler who wants to get Mean Time and, if possible, Summer Time, my conclusions are:

- 1] Best is the Equatorial Adjustable Sun Clock (see page 109).
- 2] For the Horizontal and Vertical Dials
 - a] if you want to be 'scientific' try the Herbert Adjustables.
 - b] if you want something very simple try the Housewife's Trick (and the more I see of it the more I like it).
- 3] for the Elliptical and Polar Dials see pages 140 and 143.

Equation of Time

This has been explained in general terms on page 41, and there is more about it under 'Marking'. Here is a more detailed picture of the Sun's strange facts of life.

The central cross-line shows the number of minutes (and degrees) the Sun is slow (on the right) and fast (on the left) on the clock, on the dates shown above and below. Broadly speaking, the Sun is mainly *slow* in the *first* six months of the year and mainly *fast* in the *second* half. He is never more than 3 minutes fast from January to June, never more than 6 minutes slow from July to December (and that in July and August only). That 6 minutes is the highest in the summer months, so the summer dialler has no great complaint. In the winter, though, the Sun is as much as 16 minutes fast, in October and November.



The Equation 'Egg'

I have never been drawn to it, but perhaps I should mention one old method of coping with the Equation of Time. More than one expert has explained how 'to construct a sundial which *at noon* on each day of the year will show true mean time'. This involves calculating the altitude and the azimuth of the Sun for one day every month (one writer says 'every day of the year'). With this information you draw on the meridian line of your dial a picture of the curve of the equation of time through the year, which looks like an anaemic figure of eight or a very

thin large egg attached to a very thin small egg. On this you mark the first of every month, and when the noon shadow falls on the appropriate point of an egg it will be noon by the clock. Since this is helpful only at noon I feel it is hardly worth the labour. Better methods are available - i.e. the 'adjustable' Dial.

'Universal' Horizontal (or Vertical)

We must walk before we run: and so I have dealt with the Horizontal (and in the next pages the Vertical) on the ancient principle that every dial must be made to fit the local latitude, and therefore is useless in any other.

First, the style must be at the angle of the latitude (or, in the Vertical, co-latitude).

Second, the hour-lines must be drawn at angles which, again, are dictated by the latitude (or co-latitude).

I have not attempted it myself, but my British Modern Sun Clocks Company will tackle it, I hope - and so, if you are a better workman, may you - a 'Principal' Dial which can be made to serve in any latitude.

So far, we have coped with the Equation of Time by rotating the *dial*: but we have left the style and the hour-points alone. Why should not these be made 'adjustable' too?

First, we must have a style on a strong hinge, and at the base of it a small latitude gauge, so that we can set the style at any required angle.

Second, the hour-points must be movable. Take a 6-inch protractor, say, and mark off every degree round the rim of your circle (or semi-circle). Then dig a little groove or channel close to the circle of degrees (I shall never do this myself). Then make your hour-points. These will be like little buttons with 1, 2, and 3, etc. on them, and they have perpendicular stalks so that they can be fixed firmly in anywhere in the groove. Then if you are moved from London to Gibraltar instead of sighing: 'I shall have to make another vertical' you will simply change the angle of your style to $33^{\circ} 52'$ (or near it) and shift your hour-points. 7 will go from $66^{\circ} 42'$ to $71^{\circ} 40'$ - 10 will go from $19^{\circ} 46'$ to 25° , and so on.

You will have tiny markers for the halves and quarters too: these you will place at sight according to the number of degrees in each hour.

The Company should export a lot of these. But they must enclose a Table of Angles with every dial (see pages 79 and 94).

VERTICAL DIAL - ADJUSTABLE

Formula for Hour-lines: $\log \tan H = \log \tan h + \log \sin \text{Co-Latitude}$ (or $\log \cos \text{Latitude}$).

Rees (1820) says:

DIAL, Vertical, is that drawn on the plane of a vertical circle.

Of these there are several varieties according to the vertical pitched upon. The verticals chiefly used are the prime vertical [East and West] and the meridian [North and South] from which respectively arise south, north, east and west dials.

Dials which respect the cardinal points of the horizon are particularly called *direct* dials. If any other vertical be chosen the dial is said to 'decline' (of which more later).

You and I will generally be content with a *direct* South dial.

The Vertical has the merit, important in a time-piece, that you can read it from a distance, whether it is on a wall, a pedestal, or a table.

Dial. The sage speaks of a 'circle'. But it can, if you like, be a semi-circle, which saves space. In each case you draw your hour-lines from the point where the style emerges from the wall. The full circle will give you the hours before and after 6. With a semi-circle you will have only the hours from 6 to 6, but that, as I have said, is enough for most of us.

If you are content with Sun Time you can draw your dial on the wooden wall. But if you wish to have a Herbert Adjustable your semi-circle must be a separate piece screwed to the wall at the base of the style and pivoting on that point.

The *style* must leave the face at the angle of the *Co-Latitude*, e.g. 90° minus Lat. $51^\circ 30' = 38^\circ 30'$. As in the Horizontal it is then parallel with the Earth's axis. You can think of it as pointing to the *South Pole*.

It can be a solid piece of wood glued to the face or some sort of rod - a knitting-needle - or a thread.

For very fine accuracy a thread is the best and its slender shadow is good to see. But I find it the devil to arrange. If your dial is 'adjustable' the thread should strictly go through the same hole as the screw which fastens the dial to the wall,

and then it doesn't last long. You should have, I suppose, a special hole for the thread just above the dial. But you will have your own answer to the problem.

If you do not want navigational accuracy – and in the garden you won't – the shadow of the thread may be too slender, and with a faint Sun difficult to see. The rod (say, a steel knitting-needle) throws a bold shadow, readable yards away. For this you will have to have a special hole in the wall just above the pivoting point of the dial. The lower end can be anchored firmly in the flat below, and if you have a Double Dial (see later) it can be anchored in the centre of your Horizontal and be the style of both.

For marking the Hours see 'Marking' (page 53). For the 'Universal' Vertical see page 88.

With a dial facing due South all this is easy. Our fathers had verticals facing all round the compass, East, West and even North. These were show-pieces, and we shall not want to follow them. But supposing your house, church, or Town Hall does *not* face due South but 30° to the West of South, say, or 20° to the East, and you want to put up a vertical dial. If you do, this will be a 'declining' dial, and that 30° will be the 'declination'. There are many old ones on the walls of churches and I have always wondered how they were done. In the Gatty book there are instructions, with diagrams, both for East and West 'decliners'. In the Rees Cyclopaedia (1820) there are some elaborate and difficult directions for drawing 'a vertical declining dial trigonometrically'. There are no straight, simple formulae such as we find in modern books, but intimidating passages of prose like this:

4. The angle of the difference of longitudes, and that of the axis with the substyle, being given; to find the angles formed in the centre of a vertical declining dial, between the substyle and hour-lines.

This problem admits of three cases; for the hour-lines, whose angles are sought, may be either, 1. Between the meridian and substyle; or, 2. Beyond the substyle; or, 3. On that side of the meridian where the substyle is not. In the two first cases, the difference is to be taken between the sun's distance from the meridian that hour, and the angle of the difference of longitudes found by the last problem; and in the third case, the sum of those two angles is to be taken, and the following canon used.

Canon. As the whole sine is to the sine of the angle between the axis and substyle, so is the tangent of the difference of the sun's distance from the meri-

dian, and the difference of longitudes, or of the sum of those two angles, to the tangent of the angle required.

I have seen no such instructions anywhere else, so I laboured long to translate them and think that I succeeded. I took the facts in Mrs Gatty's diagram (Latitude 54° N and 'Declination' 30° W) and applied the 1820 instructions to them. After an exhausting struggle they seemed to fit. Any really keen dialler, I feel, should master them too. You might want to fix one on the wall of a greenhouse, or the dairy.

To draw a Vertical Dial - 'declining' West 30° - Latitude 54°

The angles I found at last, after much time and toil, seem to be very close to the angles in the diagram. Either the diagram or my protractor work may be fractionally faulty but there seems to be no doubt that the formulae are sound.

To save labour for those who come after I will summarize - and for those who have the Gatty book, or live in Latitude 54° , I will risk giving my answers.

The 'declination' is 30° West. So your substyle will be East of the meridian line.

Dec. = Declination (30°) Co-Dec. = its complement (60°)

Lat. = Latitude (54°) Co-Lat. = Co-Latitude (36°)

H = Hour-line

h = distance of the Sun (e.g. at I or II - 15°)

K = any required angle

A *For the angle between the meridian and the substyle*

$$\log \tan K = \log \tan \text{Co-Lat.} + \log \sin \text{Declination} \quad 19^{\circ} 58'$$

B *For the angle between the substyle and the Axis (of the instrument?)*

$$\log \sin K = \log \sin \text{Co-Lat.} + \log \sin \text{Co-Declination} \quad 30^{\circ} 36'$$

C *For the 'difference of longitudes' between the meridian of the place and the meridian of the plane (i.e. the dial)*

$$\log \tan \text{complement of } K = \log \sin \text{Lat.} + \log \tan \text{Co-Declination} \quad 35^{\circ} 31'$$

(Subtract the answer from 90° to get K, 'the difference of longitudes'.)

D For the angles between the substyle and the hour-lines

1] The hour-lines between the meridian and the substyle

2] The hour-lines beyond the substyle

For both (1) and (2) first take the difference between h and C

Then

$\log \tan K$ (the angle we require)

$$= \log \sin B + \log \tan (\text{difference between } h \text{ and } C)$$

e.g.

$$\begin{array}{rcl} \text{Hour I} & B = 30^\circ 36' & C = 35^\circ 31' \\ & & h = 15^\circ 0' \\ & & \hline & & 20^\circ 31' \end{array}$$

$$\log \sin 30^\circ 36' \quad 9.70655$$

$$\log \tan 20^\circ 31' + \quad 9.57312$$

$$\log \tan K = \quad 9.27967 = 10^\circ 47'$$

$$\begin{array}{ll} \text{(1) Hour I} & 10^\circ 47' \\ & \text{II} \quad 2^\circ 49' \end{array}$$

$$\begin{array}{ll} \text{(2) Hour III} & 4^\circ 51' \\ & \text{IV} \quad 13^\circ 3' \\ & \text{V} \quad 22^\circ 45' \\ & \text{VI} \quad 35^\circ 29' \\ & \text{VII} \quad 53^\circ 40' \end{array}$$

3] The hour-lines on that side of the meridian where the substyle is not (in this case the West side).

Here you *add* C and h .

$$\log \tan K = \log \sin B (30^\circ 36') + \log \tan (C + h)$$

$$\text{Hour XI} \quad 31^\circ 47'$$

$$\text{X} \quad 48^\circ 11'$$

$$\text{IX} \quad 71^\circ 50'$$

$$\text{VIII} \quad 100^\circ 44'$$

(You must do this. $C + h$ comes to $95^\circ 31'$ - and I took $\cotan 5^\circ 31'$. The result looks right in the diagram.)

D, then, gives the angles between the hour-lines and the substyle. Now, at last, we come to our real goal:

E *The angles between the hour-lines and the meridian*

1] The hour-lines between the meridian and the substyle. (These hours in the Gatty diagram are I and II.)

$$H = A \text{ minus } D$$

$$\text{I } 9^{\circ} 11'$$

$$\text{II } 17^{\circ} 9'$$

2] The other hour-lines on the substyle side.

$$H = A \text{ plus } D$$

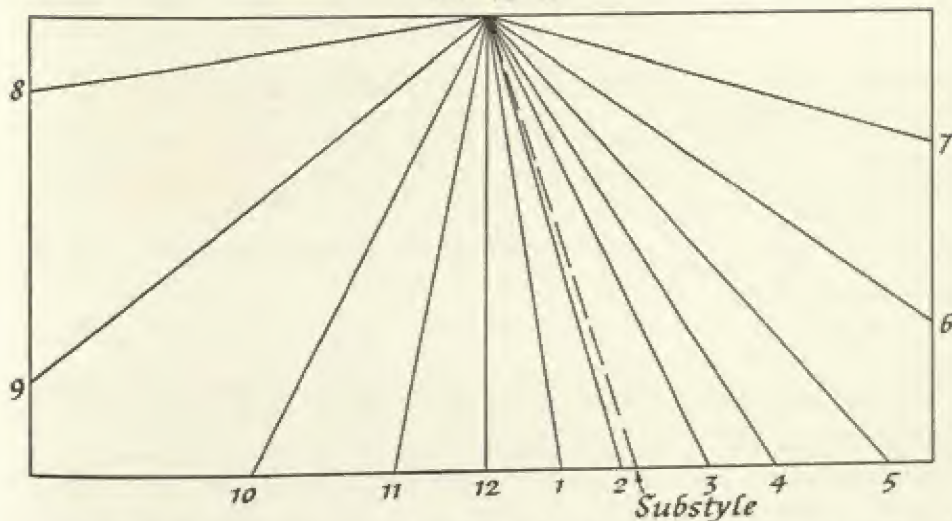
$$\text{III } 24^{\circ} 49'$$

$$\text{IV } 33^{\circ} 1'$$

$$\text{V } 42^{\circ} 43'$$

$$\text{VI } 55^{\circ} 27'$$

$$\text{VII } 73^{\circ} 38'$$



Hour-lines, found trigonometrically, as described, for a VERTICAL DIAL declining 30° West in Latitude 54° North (the Dotted Line is the line of the substyle).

3] The hour-lines on the other (West) side of the meridian.

$$H = A \text{ minus } D \text{ or } D \text{ minus } A$$

XI	11° 49'
X	28° 13'
IX	50° 52'
VIII	80° 46' (?)

How you draw such angles on the wall of a church I cannot say: but evidently they can.

Here are the hour-angles, for various latitudes, for the ordinary South-facing vertical dial (formula $\log \tan H = \log \tan h + \log \cos \text{Latitude}$). I do not prepare these very laborious tables merely to save you trouble. I find them instructive, and

$$\text{Formula: } \log \tan H = \log \tan h + \log \cos \text{Latitude}$$

Angles to be drawn from the base of the style of a Vertical Sundial to mark the hours of:

<i>Latitude</i>	<i>11 a.m. 1 p.m.</i>	<i>10 a.m. 2 p.m.</i>	<i>9 a.m. 3 p.m.</i>	<i>8 a.m. 4 p.m.</i>	<i>7 a.m. 5 p.m.</i>	<i>6 a.m. 6 p.m.</i>	<i>Difference between 6 and 7</i>
7° N							
(Colombo 7° 56' N)	14° 53'	29° 49'	44° 47'	59° 49'	74° 53'	90°	15° 7'
9° N (Addis Ababa)							
(Panama Canal 9° 10' N)	14° 49'	29° 41'	44° 38'	59° 41'	74° 49'	90°	15° 11'
15° N							
(Khartoum 15° 35' N)	14° 30'	29° 9'	44° 0'	59° 8'	74° 30'	90°	15° 30'
18° N (Jamaica)							
(Bombay 18° 55' N)	14° 18'	28° 46'	43° 34'	58° 44'	74° 14'	90°	15° 46'
25° N							
(Cape Kennedy, Nassau, Miami 25° 46' N)	13° 39'	27° 37'	42° 11'	57° 30'	73° 31'	90°	16° 29'
30° N (New Orleans, Suez)	13° 3'	26° 34'	40° 53'	56° 18'	72° 48'	90°	17° 12'
32° S (Cape of G. Hope)	12° 48'	26° 5'	40° 18'	55° 45'	72° 28'	90°	17° 32'
34° S							
(Sydney 33° 52' S)	12° 31'	25° 35'	39° 39'	55° 8'	72° 5'	90°	17° 55'
36° N (Gibraltar)	12° 13'	25° 2'	38° 58'	54° 29'	71° 40'	90°	18° 20'
38° N							
(Melbourne 37° 48' S)	11° 55'	24° 27'	38° 14'	53° 41'	71° 13'	90°	18° 47'
40° N							
(New York 40° 43' N, Wellington 39° 45' S)	11° 36'	23° 51'	37° 27'	53° 0'	70° 42'	90°	19° 18'

Angles to be drawn from the base of the style of a Vertical Sundial to mark the hours of:

Latitude	11 a.m. 1 p.m.	10 a.m. 2 p.m.	9 a.m. 3 p.m.	8 a.m. 4 p.m.	7 a.m. 5 p.m.	6 a.m. 6 p.m.	Difference between 6 and 7
42° (Rome 41° 54' N)	11° 15'	23° 13'	36° 37'	52° 8'	70° 10'	90°	19° 50'
45° (Bordeaux - Milan)	10° 43'	22° 12'	35° 15'	50° 46'	69° 15'	90°	20° 45'
50° (Lizard - Land's End)	9° 46'	20° 27'	32° 44'	48° 4'	67° 22'	90°	22° 38'
51° (Taunton - Sussex)	9° 34'	19° 58'	32° 11'	47° 32'	66° 56'	90°	23° 4'
51° 30' (London)	9° 28'	19° 46'	31° 54'	47° 9'	66° 42'	90°	23° 18'
52° (Banbury - Ipswich)	9° 32'	19° 34'	31° 37'	46° 50'	66° 29'	90°	23° 31'
53° (Nottingham)	9° 10'	19° 9'	31° 2'	46° 11'	66° 0'	90°	24° 0'
54° (Lancaster - Harrogate)	8° 51'	18° 44'	30° 17'	45° 30'	65° 30'	90°	24° 31'
55° (Newcastle)	8° 44'	18° 19'	29° 50'	44° 48'	64° 57'	90°	25° 3'
56° (Firth of Forth)	8° 31'	17° 53'	29° 12'	44° 5'	64° 24'	90°	25° 36'
57° (Inverness)	8° 18'	17° 27'	28° 34'	43° 19'	63° 48'	90°	26° 12'
58° (Sutherland)	8° 5'	17° 0'	27° 55'	42° 33'	63° 10'	90°	26° 50'
59° (Orkneys)	7° 51'	16° 33'	27° 15'	41° 44'	62° 31'	90°	27° 29'
60° (Hebrides)	7° 37'	16° 6'	26° 33'	40° 53'	61° 48'	90°	28° 12'
70° (North Cape)	5° 14'	11° 10'	18° 53'	30° 38'	51° 55'	90°	38° 5'
80° (Spitsbergen)	2° 39'	5° 45'	9° 51'	16° 44'	32° 57'	90°	57° 3'

so may you. They reveal the nature and habits of each breed of dial as a single set of angles cannot do. For example, we saw (on page 79) that a Horizontal sundial would be quite unsatisfactory at Colombo (7° North) or anywhere near the Equator. All the hour-lines are huddled together round the meridian, and there are only $22\frac{1}{2}$ degrees between I and V. The Vertical, though, as you might expect, works beautifully in Latitude 7°. The hour-divisions are nearly equal - 14° 53',

$14^{\circ} 56'$, $14^{\circ} 58'$, $14^{\circ} 24'$, $15^{\circ} 41'$, and $15^{\circ} 17'$. So if my old friends in Colombo put up a great Town Herbert - Vertical - Adjustable it should work very well.

Note, too, that a Vertical would be a poor servant in the Arctic Circle. But a Horizontal is at its best in 80° North, Spitsbergen. All the hour-divisions are close to 15° .

Note, finally, that in English Latitudes the differences are not great. Between 50° North (Land's End) and 55° North (Newcastle) the difference at 1 o'clock is less than a degree, and at 5 o'clock just under 2 degrees. Still, you had better be right.

'SPOT' DIAL - OR CEILING CLOCK

This is, I think, the one form of dial not mentioned by the Sage of 1820. But I have had some fun with it. It has high merit: but it demands the heart of a lion.

Here the time is recorded not by a moving shadow but by a moving circle of light. You fix, flat, a small mirror in the window (that thing in your wife's handbag will do). The mirror is covered with paper except for a small round hole. The Sun shines on the small round hole, the light is reflected on to the ceiling, and all the morning (if the room looks South or thereabouts) a tiny Sun marches across the ceiling. In one of those L-shaped lounges it would march through the afternoon as well.

This is delightful - and practical too. The literary (or business) man hunting a word, or a new idea, leans back in his chair and stares at the ceiling. He sees his own little Sun approaching 11.30. It may not inspire him, but it reminds him sharply of the passage of time - his *own* time - and the wonders of Creation, of the blessings of life: and he returns to work with a will.

But this is not, like the garden dials, easily arranged. The Sun's light is reflected to the ceiling at exactly the same angle at which it hit the mirror. That is the trouble. For the ceiling Sun, like its great father, is never in exactly the same position on two consecutive days. In June when the Sun is high, the spot will be near the window, in August out in the middle of the ceiling, in the winter far away towards - or even down - the opposite wall. In the garden you mark a spot on your circle '11', and you are ready for 11 o'clock for ever more. On your ceiling you must have a long line for 11, and 11.15, and 11.30, for your Sun will cross that line at a different point each day. The labour of establishing these lines should only be attempted by young athletes in good health. Isaac Newton did it, I believe, and Christopher

Wren: but both were boys. This amateur maniac took it on at the age of 66. It means much standing on the tops of step-ladders with a wrist-watch, waiting for the calculated moment when you will prod the heart of your small Sun with a pencil. Half a minute before that moment, as likely as not in this dear land, a passing cloud obscures the real Sun and extinguishes yours, and you must postpone that particular marking till tomorrow. You spend much money dialling TIM and checking your watch by the 'pips', and for each pencil mark you must turn Greenwich Mean Time into Apparent, or Sun, Time, allowing for the Equation of Time and the Longitude (see 'Marking', page 53). In the end, if you do not fall from the ladder and break a limb, you will have rather ragged lines of pencil dots all over the ceiling. These you will marry and extend, first, with long lengths of string, that is, if you have the fitness and fortitude to fasten long lengths of string to a ceiling, with a hammer and drawing-pins, from the top of a step-ladder. It is rough work. Then the lines must be tastefully painted – red for the hours, perhaps, blue for the half-hours, and yellow for the quarters. There can be cross-lines too, marking the months, and against the months a note of the Equation of Time, 'Sun 6 minutes Slow', etc., which would make all plain. There should be room, too, on the farther ceiling, where the lines spread wider, for some decorative legends – the Latitude, the Longitude (which all should know, but rarely do), the name of the dialler HOC FECIT HERBERT – and so on. I never reached this rewarding stage of the work, for I was ejected from the study and my strings were cruelly torn down. But I commend the Ceiling Clock to any spirited house-husband who would care to join the company of NEWTON, WREN, and HERBERT. If I were a fashionable Interior Decorator I would make the Ceiling Clock part of my service. There would be a special staff, two or three vigorous young, with a head for heights and some acquaintance with astronomy and painting. I am available for hire myself as an adviser, but not for ladder-work.

Nor need this Clock be a plaything for the rich alone. We cannot all have lawns and gardens. But the Sun comes sometimes into nearly everybody's window. The lonely scribbler or artist in his attic can for nothing have the company of a watchful, wandering Sun on his ceiling; and if his attic is humble enough he will not have to stand on step-ladders. If I were given a long turn in prison the first thing I should do would be to start a Ceiling Clock. They might not let me have a mirror: but somehow I should find a way. A watch might do.

The Ceiling Clock would be splendid for a pub with a long bar – and very often

the long bar goes round a corner. What happy arguments I hear among the customers: ‘Don’t show your ignorance, mate. Can’t you read? The Sun’s five minutes *fast*. Time for another pint.’ There might, too, be some happy arguments with the landlord (or the police) as there were over my Sundial Table at the local in seasons when the Sun was *slow*. ‘Five minutes *to*, that clock says, officer. That’s God’s time – there ain’t no better.’ As I have said, Greenwich Mean Time (or, alas, Beastly Summer Time) is the legal time for all purposes. But how is a simple beer-drinker to know that? Even a constable might be held in argument for long enough to avert any repressive action.

EQUATORIAL

Formula for Hour-lines: $H = h$

This (in the Herbert editions) is my favourite. Most books dismiss it as a venerable curiosity: but the Sage of 1820, who calls it an ‘equinoctial’, begins with it: ‘DIAL equinoctial, is that described on an equinoctial plane, or a plane representing that of the “equinoctial” [which means, you remember, the “celestial equator”]. The equinoctial is the first, easiest, and most natural of dials . . .’

It is not the simplest to construct, but it is the most rewarding. It has three or four prime virtues. As in a clock, the hour-divisions are uniform. It is tilted up (unless you are at the North Pole) at this angle or that, and so can be read at a distance. It is easily adjustable, with no new sums, trigonometry, or material change; and so can be used in any latitude.

Dial. It is a circular dial, marked in 24 equal hour-divisions. 12 (midnight) is at the top and 12 (noon) at the bottom. The 12 hours after midnight come down the right-hand side; the afternoon and early night hours climb up the left-hand side. You may think at first that the upper semi-circle hours are not likely to be much use: but wait till we get to the Herbert Sun Clock.

Marking. This looks delightfully easy – but, to me, at least, it is not. That is, accuracy is far from easy.

The Sage of 1820 says happily, in his cook-book style:

From a centre, *C*, describe a circle *ABDE*, and by two diameters *AD* and *BE*,

intersecting each other at right angles, divide it into quadrants, *AB*, *BD*, *DE* and *EA*. Subdivide each quadrant into six equal parts, by the right lines, *C-I*, *C-II*, *C-III* etc., which lines will be hour-lines. Through the centre drive a style, or pin, perpendicular to the plane *ABDE*.

He is quite right, of course. But let me translate – for the benefit of the garden amateur – like me.

First draw your circle. What size? For special reasons which will emerge later I suggest a diameter of 6 inches – radius 3.

'First draw your circle.' (But before that make sure that your centre *C* is exactly in the centre of your 'plane' – the piece of wood on which you are going to draw your dial. Whatever the size and shape of your 'plane', it is best to have just the same distance between the sides of it and the circumference of your circle (North and South – East and West).)

Now, the most important thing of all, your 'meridian line', the line that runs North and South through your centre, *C*. After years of effort I still find it difficult to do this precisely with ruler and protractor: I have only recently acquired a small 'Engineer's Square' – and I recommend it.

Then, at right angles to the meridian, draw your East and West line. You now have four 'quadrants' or quarter-circles. You divide each of these into 6 equal divisions – i.e. 15° each. This I have always done (for want of a better way) by laying a protractor on the dial, making little dots at the 15° intervals, all round, and drawing lines through the centre and the dots. It is extraordinary what inaccuracies can result, though you take the greatest care. I have heard of something called a Scale of Chords, which does the work better, but I never met one. The Sage, observe, offers no assistance. He takes accuracy for granted.

I have often thought sadly that a real mathematician would be able to mark out what the width of each arc should be, and measure them off with dividers – or what the sage calls 'the compasses'. But I was weaned from these affairs before we got to π , and π has always frightened me. Today, though, for your benefit, I have unearthed a school-book and discovered π . (See how tenacious an old man can be!)

π , they say, is always $3\frac{1}{7}$ or 3.14.

If *C* is the circumference of a circle and *r* is the radius

$$C = \pi \ 2 \ r$$

My earliest and loveliest Equatorial has a radius of 6 inches, so I thought I would find its circumference and divide by 24.

$$C = 3.14 \times 2 \times 6$$

I made this 37.6992 inches: and, dividing it by 24, I got 1.57 inches, for each hour.

To my surprise, this is just the span (according to 'the compasses') of my hour-divisions (most of them).

For a radius of 3 inches (which is going to be yours) I made the span 0.785 inches.

But don't forget 1.57, for that covers *two* hours of your 3-inch radius dial, and may be more accurate.

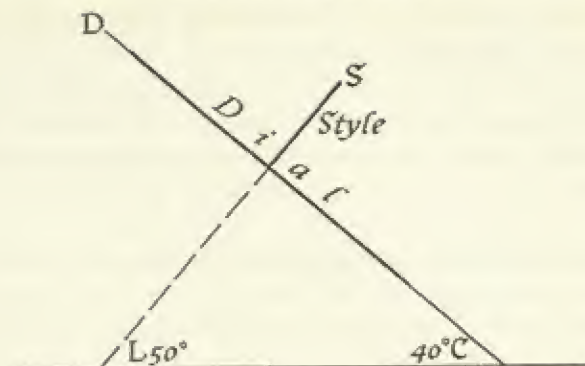
I dare say your mathematical master will say that there is a snag in this and will give you something better. But it is the best that I can do.

You see the advantage, by the way, of a dial whose hour-divisions are *equal*. I don't see how π would assist you with a horizontal.

There is another way. Draw a straight line *AB* at the bottom, at right angles to your meridian line, *ML*, which it meets at *L*. *ML* is, say, 7.3 inches long, and you want the Hour-lines for 11 and 1. The angle (see the Table) is $9^{\circ} 28'$. The 1 Hour-line will hit *AB* at *H*. How far from *L* will *H* be? The sum is this:

$$\begin{array}{rcl} LH = \text{length of } ML \times \tan 9^{\circ} 28' & & \\ \log 7.3 \text{ inches} & & 0.86332 \\ \log \tan 9^{\circ} 28' & & + 9.22205 \\ \hline LH & = & 0.08537 = 1.21 \text{ inches} \end{array}$$

Style. This is perpendicular to the dial, at its centre. It points, as usual, to the Pole, and represents the Earth's axis. So the dial, to which it is perpendicular, must represent the Equator. If you imagine - and in rare cases, you may have this in fact - the style extended Southwards or downwards through the dial to the ground, or the base of the instrument, it will hit the ground at the angle of the latitude. The dial will leave the ground at the angle of the *co-latitude* - thus:



Latitude 50°

CD is the line of the dial; *SL* the line of the style; *L* is the angle of the latitude – 50° ; *C* of the co-latitude – 40° . *C*, in practice, is the important angle: for here your dial must be fixed, or, more often, hinged. In all cases make sure that you get the angle *C* right. From that all else follows.

Now for action. You can do various things. But let us go slow. You know the old Army story of the Sergeant-Major who is teaching recruits to fix bayonets and says: 'When I say "Fix" – you don't fix – see?' It is quite true (I was an active witness, though in naval circles, many times); and it is quite sensible: 'Fix' is a 'cautionary word'. Thus, I propose to give you the drill by stages, assuming, if I may, that you know no more than I did when I began. But stages (1) and (2) are 'cautionary words'. Some of the instructions will be useful at all stages but do not rush into action, whatever I say, at Stage One. Wait till Stages 3 and 4 when the Herbert Magic begins.

Stage 1. Fixed Equatorial. If you are a stay-at-home, not likely to change your latitude, and you want Sun Time only, the thing is easy. Draw your dial on a plain, or painted piece of wood (or, if you have one, of course, on a sheet of brass). Make a little hole in the centre and insert your style. In your first modest days a needle, half a knitting-needle, or a cocktail stick will do. Then prop your dial up

on another piece of wood (which I will call the 'base') at the angle of the co-latitude, which you will measure with a protractor. Give it a perpendicular support somewhere, and there you are. (With a drawing on some squared paper, or indeed unsquared paper, you can measure just what length the support should be and where it should stand.) But this would be a mean-spirited effort, and I shall not encourage it.

Stage 2. Universal. 'Universal', as applied to a dial, means that it can be used anywhere without organic alteration. To make the most of this quality you must be able to move your dial up and down so that it can do the same work in any latitude. It must be capable of taking any angular pose from 0° to 90° . At the North Pole, if you go there, it will lie flat on its base. Over the Equator it will stand perpendicular - 90° . So it must be hinged to a base at C. This means a good deal of drilling holes and driving screws. Two hinges are best: and I hope that you are better than I am at getting the hinges level and the whole thing dead along a given line.

If your dial is a little one - quite a small equatorial can do good service - and your hinges are tough, it may remain at the required angle without support (test your brass hinges when you buy them). But this is uncertain and it will not do for a substantial piece.

Support

The problem is a double one - to provide a support for the dial which can be adapted to any change of angle it may have to make. A perpendicular from the base will do, if it can be shortened or lengthened. I have tried yachtsman's 'rigging-screws' which answer pretty well. Or you can have supports hinged on the base, and alter their angle as the dial's angle alters. Or you can have a screw, thrust through the dial-piece, but below the dial, and holding all in position. None of these is quite satisfactory. I find that when I am showing off - 'This is how you change the thing from one latitude to another' - there is a good deal of frustration. I turn the rigging-screw the wrong way; the perpendicular support slips and everything collapses. You, no doubt, will have better ideas. By the way, in any case, I screw a protractor to the side of the instrument with its middle alongside C, so that I can judge the co-latitude angle correctly. This is not so easy as it sounds.

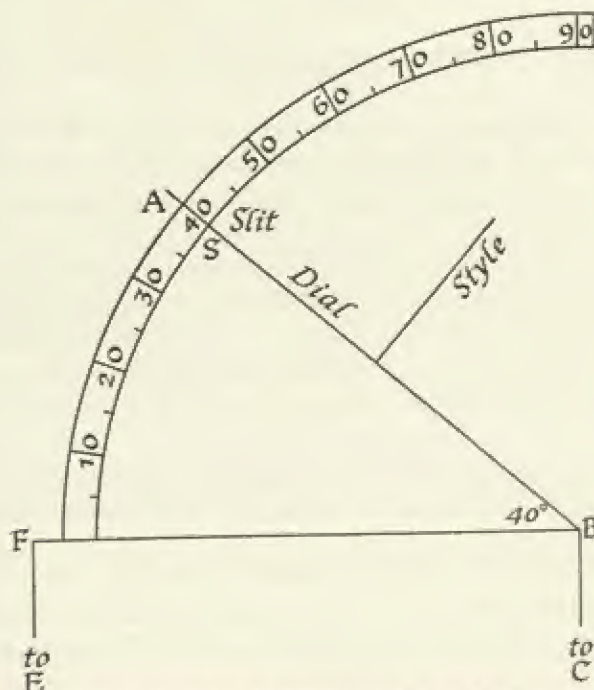
By far the best arrangement I have seen is in a picture in the 1820 book. The Sage's instructions say: *'Join two metal, or ivory planes, ABCD and BCEF, so as to be movable at the joint.'*

In other words *ABCD* is the 'plane' on which the dial is drawn. *BCEF* is the base; and they are hinged along *BC*.

In the back right-hand corner of the base (*F*): *'Fit in the same plane a brass quadrant nicely graduated, and passing through a hole cut in the plane ABCD.'*

Don't be alarmed. They were better off in those days. 'Metal, ivory, and brass' are not compulsory, though I should dearly love to see some of my devices done in these materials. You and I may be, must be, content with wood – or plastic?

I cannot draw the whole instrument, but here is a rather attractive picture of the right-hand or West side, seen side-face, so to speak, from the other flank. The



Quadrant passing gracefully through a slit in the Equatorial Dial
Latitude 50° – Co-Latitude 40°

Dial is set for the co-latitude of 40° (the Latitude is 50°), and the quadrant is gracefully passing through the slit in the Dial at S. Yours must be more 'nicely graduated' than mine and show, if possible, single degrees.

The radius of the quadrant must be a little less than the length of the dial 'plane' and the base, which in the picture are equal. A better carpenter than I will, no doubt, know how to plant its bottom end in the base.

Having fitted it, if you need a change of latitude, all you have to do is to slide the dial up or down the quadrant. If your dial is heavy I do not know why you should not have a quadrant each side.

The advantage of having it (or them) at the side is that it leaves the whole space under the overhang free to play with. I like myself to put other instruments there, or another dial, but we shall come to that later.

I disagree with the Sage's arrangement in one particular. The base, I think, should be longer than the Dial-plane, so that you have space to play with at both ends - room for a compass, a Herbert Height-finder, etc. Also this way the instrument has more dignity.

This, but not quite so much, is what I got from the books. Now, we have a 'Universal' Dial, which can be used in any latitude. But we are still telling Sun Time. We want Clock Time. But the Sage does not help us here.

Stage 3. You will see now why I said 'Wait'. Do not do any drawing on the 'plane' you have prepared. Draw your 24-hour Dial on a separate - say, 6-inch - circle of wood, or hardboard, and make a hole in it dead-centre. The hole must be made to fit the style exactly - don't let it be too large - for your Dial is going to be rotated round the style, and this will give you Mean Time, Summer Time and other blessings.

We come now to:

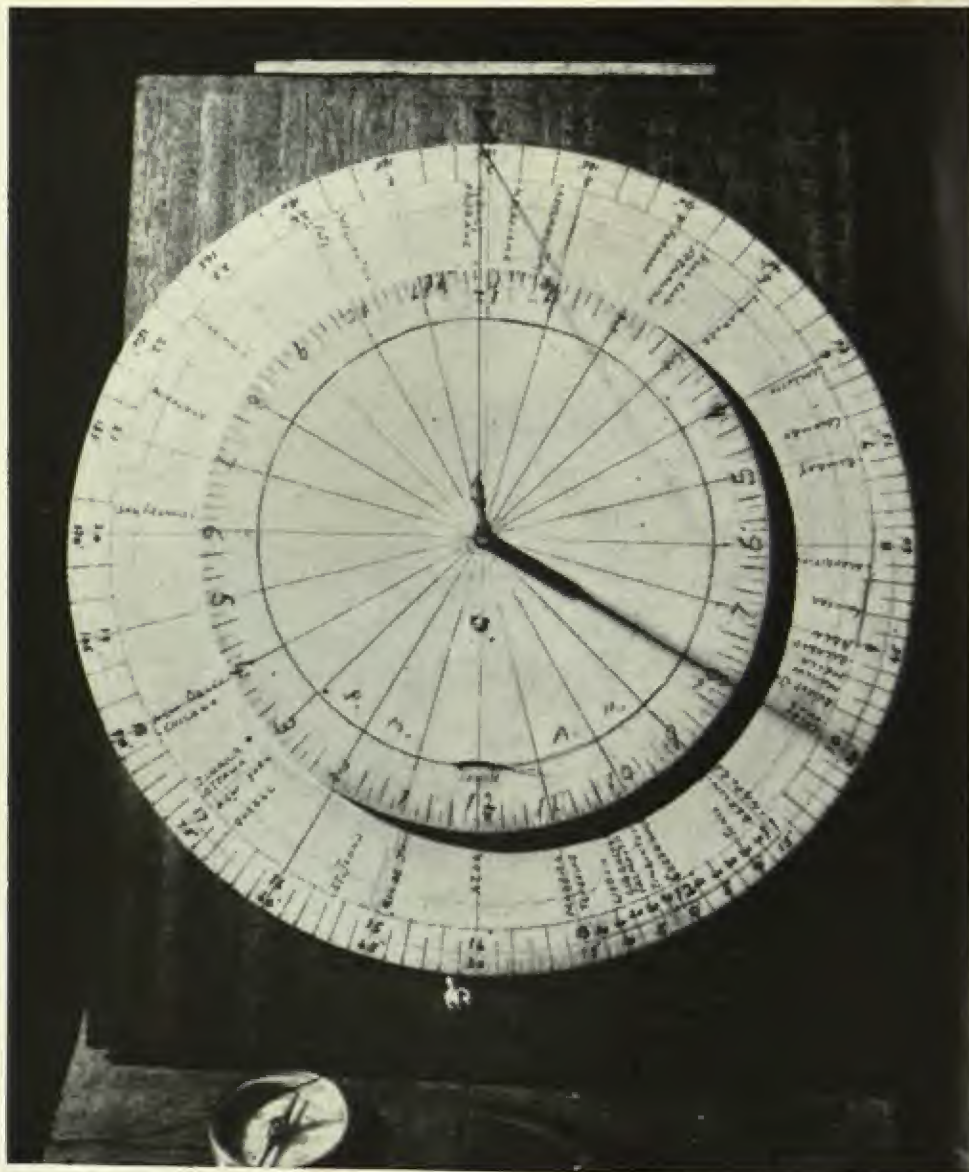
Stage 4. The Herbert Universal, Adjustable Sun Clock (Model One)

I modestly suggest that there has been no instrument quite like this before. But to this shy statement I will return when we come to Part II and my halting navigational claims.

First, I must break it to you that you are now required to draw a second dial, larger than the first - say 7 inches. This, for the sake of clarity, I will call the Ring.



4. SUN CLOCK (Model One) - Plan. The shadow shows 9 a.m. Local Mean Time on the Dial. G.M.T. 2 p.m. has been moved onto the meridian line and the longitude 75° West is under the shadow. *Electric light.*



5. SUN CLOCK (Model Two). The shadow (*electric light only*) shows 8 a.m. Local Mean Time on the Dial and G.M.T. 10 a.m. has been put under it. Under 12 is your longitude 30° West. The very bad shadow on the right is the shadow of the second style, one of the two 'converging shadows'.

The Ring must be movable, or 'rotatable', too (yes, the word is in the O.E.D.) round the same style. If the instrument were made by professionals the movable Dial and the movable Ring would be flush with one another. In other words the Ring would be a real ring, a one-inch circlet quite independent of the Dial, like the alleged Ring round Saturn, though not so far away. You should be able to turn it this way or that without disturbing the Dial. My poor carpentering has never achieved this – and here is yet one more opening for better men. So my Dial has to be on top of the Ring, and the shadow, passing from one to the other, has had to jump down a cliff. I am not sure that this causes any serious trouble, but it is not satisfactory.

Marking. Now we come to a dividing of the ways. Your Dial (in the Northern Hemisphere) will always be marked in the same way, with the morning hours on the *right*. This shows you the time in your own little world.

The Ring represents the great world. Both Models One (Popular) and Two (Navigational) show how your time and place compare with other peoples'. But in Model I the chief emphasis is on Time: in Model II it is on Place, that is longitude. So to the ordinary garden dialler Model One will make the most appeal. Between the two there is a fundamental difference in the method of marking.

Model One

On the Ring mark the afternoon hours on the *right* – that is, under the morning hours on the Dial. It will look like this:

p.m.			a.m.			
3	2	1	12	11	10	9 DIAL
<hr/>						
9	10	11	12	1	2	3 RING
a.m.			p.m.			

It is a good trick to mark the morning hours in red and the afternoon in black.

Now, over, or under, the hours, write the appropriate degrees of longitude. Don't be alarmed – nothing could be simpler. It is 15° for each hour beginning from 0° over 12 and going up each side to 180° at the top.

Somewhere on the left write EAST – and on the right WEST.

Now go back to the Dial. Over your hours you should write again, perhaps on

a separate circle, 24 degrees of longitude. (This is not compulsory, but it will help you when you come to write the names of places, which is going to give you much fun.) They will be exactly the same figures as you marked on the Ring - from 0° to 180° on the right, and 0° to 180° on the left. But on the Dial, write somewhere WEST on the left and EAST on the right (that is, opposite to the Ring).

(If all this seems a little too complicated look at Plate 4 - facing page 104). Believe me, startling simplicity will be your reward in the end.)

The hours about noon should now look like this:

WEST				EAST				etc.	DIAL
45°	30°	15°	0°	15°	30°	45°			
3	2	1	12	11	10	9			
<hr/>									
9	10	11	12	1	2	3			
45°	30°	15°	0°	15°	30°	45°		etc.	RING
EAST				WEST					

Now, on the Dial, we bring in Place. Later (on page 119) you will find a list of principal places with their longitudes. If you want others you must look at a good Atlas.

Write on the Dial, over the appropriate degrees of longitude, what names you will. If you write more neatly than I do you can record some interesting concatenations - for example Tunis $10^\circ 10'$ E, Elba $10^\circ 10'$ E, Oslo $10^\circ 0'$ E, Dubrovnik $18^\circ 9'$ E, Stockholm $18^\circ 5'$ E. But start by pencilling a few simple ones, to make sure that you have got the drill right. Take Greenwich $0^\circ 0'$, Falmouth $5^\circ 4'$ W, Azores $29^\circ 0'$ W, New York $74^\circ 1'$ W, Aden 45° E and Sydney $150^\circ 12'$ E.

The Ring tells Greenwich Time always.

The shadow on the Dial tells your Local Time. But if you are on the meridian of Greenwich that will be Greenwich Time too.

Now then, over the meridian line you have Greenwich $0^\circ 12^h$ on the Dial; and, on the Ring 12 NOON. Look along three hours to the right. If the shadow falls on red 9 (Dial) it is 9 a.m. in your Greenwich garden. But it also falls on Aden 45° E (Dial): and on the Ring it falls on black 3 p.m. So at Aden it is 3 p.m. when it is 12 at Greenwich - and this, bless me, is right. Look to the left. When the shadow falls on Greenwich 12 (Dial) it will be 10 a.m. in the Azores as is shown on the Ring. At the same moment by looking along the thing you can see that

it is 10 p.m. at Sydney and 10 a.m. at the Azores, on the opposite side of the world. If the Sun goes in and there is no shadow the Clock will still tell the world's time everywhere. Move it about. On Christmas Day you want to ring up your son in New York, before he goes into the country. Put New York (Dial) against red 9 a.m. on the Ring. Then find Greenwich and you will see that it is over 2 p.m. on the Ring. More difficult still, you want to talk to your daughter in Sydney. What time will be convenient to both? When it is noon in London, you see, it is 10 p.m. in Sydney – rather too late. But Greenwich over red 9 a.m. on the Ring will give you 7 p.m. at Sydney. That should do.

Now, if all this comes off as promised, write in the rest of your names. Wherever you live you will have that place, that longitude, permanently over your meridian line. You live at Colombo. When it is noon in Colombo (80° E) it is, you see, only 6.40 a.m. in London – too early to ring the old folks at home. Move the Dial round till Colombo is over 6 p.m. (Ring), and Greenwich will be over 12.40 – just before lunch.

You have often sung, I expect, that fine hymn 'The Day Thou gavest', and were puzzled, as a child, perhaps, by the verse:

The Sun that bids us rest is waking
Our brethren neath the *western* sky.
And hour by hour fresh lips are making
Thy wondrous doings heard on high.

The word 'Western' puzzles me still. Put Greenwich over 8 p.m., when the summer Sun may be said to 'bid us rest', and you will see that due West, at New Orleans, it is 2 o'clock, and at New York 3 o'clock, in the afternoon, when the Sun, except from a siesta, can hardly be said to be 'waking our brethren'. Due East at Calcutta it is only 2 a.m., too early. In Sydney, though, it is 6 a.m. and in Wellington, New Zealand, nearly 8 a.m., so 'Southern' would be the better word. You may not think that it matters: but see what one glance at your Sun Clock can tell you.

All this information is available, all these clever cosmic tricks can be played even when the Sun is not shining, and should make the Sun Clock a point of interest in public park or private garden on the dullest day.

When the Sun does shine – to make all plain – the shadow shows:

a] on the Dial, the Local Sun Time

b] on the Ring, the Greenwich Time of the place at Greenwich noon.

When the Sun does *not* shine you can still read the comparative times at this and that place, all round the world, on the Ring.

Time-finder. But the prime purpose of the instrument is to tell you the time at home when the Sun is shining – and ‘the right time’.

Both Dial and Ring, note, are at present telling Sun Time. You want Clock Time (‘Mean’ or ‘Beastly Summer’).

You live, say, at Falmouth, Longitude 5° (20 minutes) West. The Equation of Time, we will say, to keep things simple, is *minus* 8 minutes (= 2 degrees). The Sun is 8 minutes behind the Clock. We had better do the old noon sum again (see page 58):

	h	m	s
Hour Angle	24	0	0
– ‘E’	11	52	0
L.M.T.	12	8	0
Long. West	20	0	(Add)
G.M.T.	12	28	0
	1	0	0
B.S.T.	1	28	0

So that will be the Greenwich Mean (and British Summer) Time of Noon-by-the-Sun at Falmouth, when the Sun, and the shadow, are over your meridian. But our Adjustable Clock does all that without sums.

28 minutes difference.

First, let us eliminate those 20 minutes of longitude. For longitude is permanent. The Falmouth Sun is always 20 minutes behind the Greenwich clock. So we bring him up to meet the clock. We do that by moving the Dial to the right till Falmouth 5° – 12.20 p.m. – is over the meridian. That is Greenwich Sun Time, as you can see on the Ring, under Greenwich (according to the drill already described).

But we want Mean Time, and there are 8 minutes to provide for. Once more the Sun is behind the Clock. Once more we move the Dial to the right – 2 degrees, 8 minutes – and bring the time shown on the Dial (shadow time) up to 12.28.

Now the shadow at Noon-by-the-Sun will show Greenwich Mean Time – on the Dial.

Under Greenwich, on the Ring, you will see 12.28 too.

Then there is Beastly Summer Time. You may prefer, as I do, to stick to Greenwich and add 1 hour. But your wife and family may insist on B.S.T. Very well. Again the Sun is behind the Clock. So you push the Dial 1 hour to the right and increase the time that he shows at noon. 1.28 on the Dial will then be over the meridian and you will be in time with the B.B.C. (NOTE – if you have set your clock to B.S.T. do not attempt any of those international comparisons unless you are sure that the countries concerned have Summer Time too.)

This may take some time to explain; but it is done in a flash, certainly much quicker than you will do that sum.

It is a little less simple, of course, if Longitude and the Equation of Time are taking you opposite ways. Suppose you are near Colchester in Longitude 1° East. The Sun here is always 4 minutes ahead of Greenwich. So you would always have 12 on the Dial, 4 minutes to the left of 12 noon and at Noon-by-the-Sun the shadow will fall on 11.56 (Dial). But now it is July 17 and the Equation of Time is *minus* 6 minutes and 4 seconds – the Sun is *behind* today. You need not even do this sum – you simply move 12 (Dial) 6 minutes to the *right*, and at Noon-by-the-Sun the shadow will fall on 12.2 (Dial). The same time will appear on the Ring under Greenwich.

You can, of course, if you wish to 'cut out the Science' simply set your Clock by your watch on 'the pips'. But I am assuming that you would like to understand the working of your instrument – and the behaviour of the Heavens.

If, at first, you are confused, do that 'E' sum again and see what your dial ought to be doing at noon. Having found the noon position you can safely use it for the other hours. But if you do it for any other hour you must use the appropriate Hour Angle – i.e. 23 hours for 11 a.m., 22 for 10 a.m., and so on:

		h	m	s
9 a.m.	H.A.	21	0	0
	– 'E'	11	52	0
	S.M.T.	9	8	0
	Long. West	20	0	
	G.M.T.	9	28	0

Longitude. Model I is chiefly designed as a time-finder, at home and abroad. But such is the magic of the great circles with which we are playing that if you insist you can get your longitude with it - in two ways:

The Rule is:

a] Put 12 (Dial) over Greenwich Time (Ring) and your longitude will appear on the Ring under the Local Time (Dial).

or b] Put Greenwich Time (Ring) on the meridian line and your longitude will appear on the Ring under the *shadow*.

In method (a) you move the *Dial*, and, as a practical matter, this may be more convenient. In (b) you move the *Ring*, but you have the intellectual pleasure, and practical advantage, of seeing your longitude indicated by the shadow.

It is difficult to explain clearly why either method should work - and at this stage it may be better not to try - but they do.

Try first with Greenwich.

The shadow falls on 10 a.m. (Local Sun Time). If you are on the meridian of Greenwich, Greenwich Time must also be 10 a.m. As a general rule, to find longitude, you confront Local Time with Greenwich Time and take the difference: but with this specially constructed Clock that will not do. Instead

a] move 12.0 (Dial) to the *left* till it is over 10 a.m. (Ring) which is Greenwich Time: then 10 a.m. (Dial), Local Time, is over 0 on the Ring, which is your longitude.

or b] move the Ring to the *right* till 10 a.m. Greenwich Time is on the meridian. Then 0° (Ring) longitude, will be under the shadow and 10 a.m. (Dial).

Now go farther afield. You saw just now that when it is 9 a.m. in New York (L.M.T.) it is 2 p.m. (G.M.T.) at Greenwich. But you learned nothing about your longitude.

You are on the last lap of an Atlantic yacht race. The shadow falls on 9 a.m. (Dial) at the moment when you learn from your chronometer, or 'The pips', that Greenwich Time is 2 p.m.

a] swiftly you put 12 (Dial) over 2 p.m. (Ring) and your longitude, 75° W, appears on the Ring under 9 (Local Time) on the Dial.

or b] you put 2 p.m. (Ring) on the meridian and your longitude (75° W) appears not merely under the Local Time (9) but under the shadow.

You are due South (or North) of the Big City.

The serious mariner will remark: 'But if your lone sailor does not know where

he is he will have to set the Clock for latitude before he can find his longitude in that clever manner. And how does he know his latitude? He is quite right; and we shall attend to that matter in Part Two. But the garden-dialler, for whom Model One is designed, does know his latitude: and so, what games he can play with his young, how much he can teach himself, with his Clock! I imagine a new form of 'Think of a number'. 'My Local Time is 5 p.m.' says Father. 'Give me my Greenwich Time, Bobby.' 'Four in the morning,' says Bobby gaily. 'Then what is my longitude? I will tell you. I am alone in 165° West between Fiji and Honolulu.' 'Oh, Daddy!'

If you do this too you will note how much easier is method (a).

One day somebody may invent an instructive game called 'Longitude'. It will have a Model One Dial and Ring on the flat – no bother about the Sun. The game will be to sail round the world westwards. With the dice you draw a Local Sun Time. Before the others can count five you must choose a G.M.T. which will give you a longitude which puts you on your way – and so on. The players will soon be astronomers and navigators. The game, no doubt, will be a minor manufacture of British Modern Sun-Clocks & Co Ltd.

Model Two (Navigational)

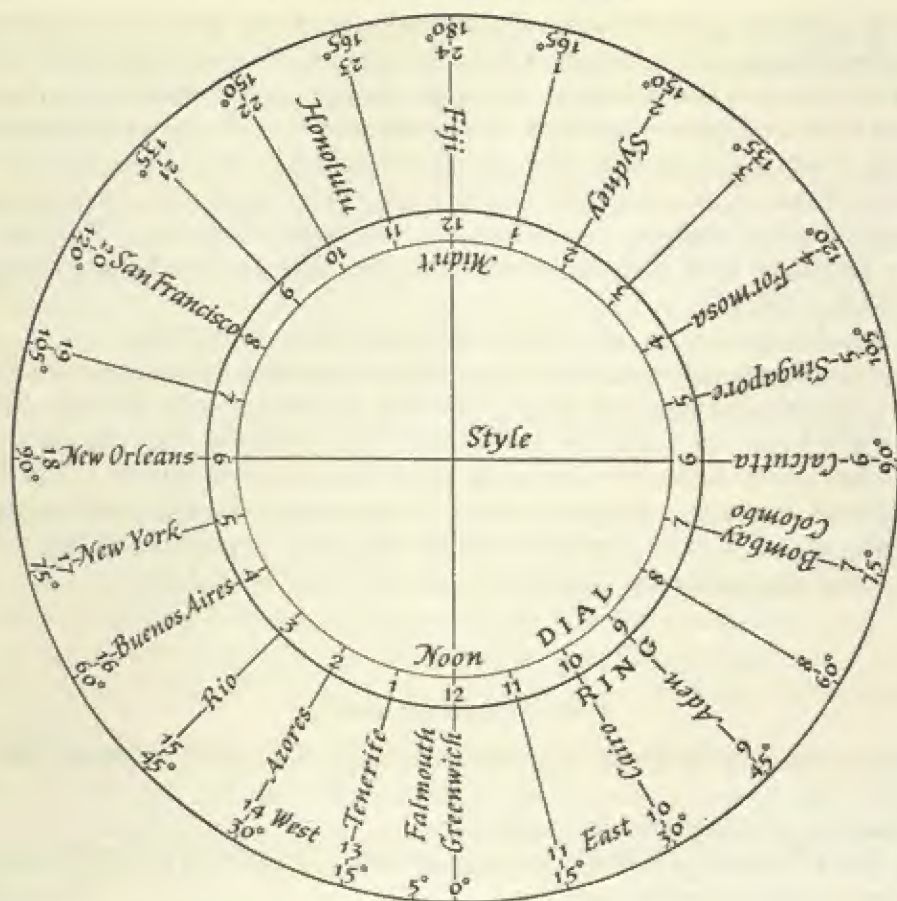
The Longitude can be found in a more seamanlike and orthodox manner with Model Two.

There are two important differences.

1] Mark the DIAL as before – morning hours to the right: *but no longitude, and no names* – these go on the RING.

2] In Model One we had the hours on the Ring running the opposite way (rightward) to the hours on the Dial (leftward). This was to make easy those comparisons of time all round the world. For the farther we go East, from which the Sun comes, though the smaller the hours of *Local* Time the larger we make the hours in terms of Greenwich Time. Set the longitude of 30° W on the meridian line of Model One. When the Sun on the Dial says 9 the Greenwich Time on the Ring is 5: when the Sun says 10 the Greenwich Time is only 4.

But in Model Two both the Dial and the Ring record the true march of the Sun. On both mark the morning hours to the right, afternoon hours to the left.



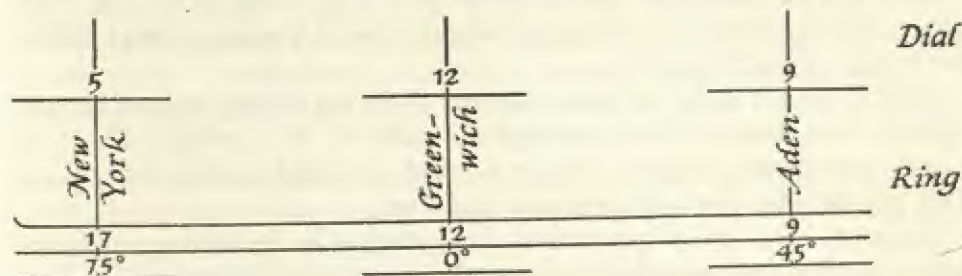
ROUGH PLAN OF SUN CLOCK - Model Two
Only full hours and 15° of Longitude marked.

But on the Ring mark the afternoon hours in continental style, 13 for 1 p.m., 14 for 2, and so on.

Then on the Ring mark the degrees of longitude both ways from 0° at the bottom. Label the degrees on the left 'West' and those on the right 'East'.

Then write what names you wish against their longitudes. Because of the names Model Two requires a little wider Ring. Diameter of 6 (Dial) and 9 (Ring) will give you a Ring $1\frac{1}{2}$ inches wide. Or you may prefer 5 and 7.

The Aden, Greenwich and New York meridians should now look like this:



Now, to get their longitude the sailors find out the Local Time by taking a sight of the Sun (and doing a multitude of sums) and then comparing Ship's (Local) Time with Greenwich Time, which they get from the chronometer – or perhaps 'the pips'. They work out the Hour Angle of the True Sun, with miles of logarithms. They subtract 'E' and get Local or Ship's Mean Time: and at the end they get this simple conclusion:

	h	m	s
Ship's Mean Time	10	0	0
Greenwich Mean Time	8	0	0
Longitude	2	0	0 = 30°

'Greenwich Time least' means 'longitude East' – so the longitude is 30° 0' East (Cairo).

The Sun Clock does all this in a flash, without any sums.

(I am imagining, by the way, that this is a moment when there is no Equation of Time – so Sun and Mean Time are the same. Usually, if you are very keen on accuracy you will first adjust the Dial so as to convert Sun Time into Mean Time.)

The shadow shows that Local Time is 10 a.m. At that moment your chronometer says 8 a.m. Greenwich Time. You do as the sailors do, and confront the two.

The Rule - as in Model One there are two methods:

a] Move the Dial to the right till 10 a.m. (Dial) Local Time, is over 8 a.m. (Ring). Your longitude, 30° East, appears under 12 on the Dial (also by the way under the shadow: but this will not always happen).

or b] you can move the Ring to the left till 8 a.m. (Ring) G.M.T. is under 10 a.m. (Dial), Local Time. Then your longitude 30° E is again under 12 (Dial), but it is not under the shadow.

Method (a) is, I think, the better. Method (b) in my Clocks, at least, is more difficult. Both methods show the longitude under 12. In a professionally made Clock I ambitiously imagine a vernier attached to 12 and moving between the Dial and the Ring. But more of that in Part Two.

Subject to 'accuracy and practicality' this I claim to be the swiftest and easiest way of finding the longitude ever invented. The serious navigator will be hard to satisfy on the point of accuracy, but then, I shall not be satisfied till they have made my instruments professionally and given me the refinements for which I ask in Part Two.

Meanwhile, without them, Model Two should be accurate enough for one of those lone mariners crossing the South Atlantic in those peaceful following Trade Winds which they never, in fact, seem to find. I have a friend who has done this twice, but he has never yet bothered to acquire a sextant or the elements of celestial navigation. You have had a storm or two before you get down to the Trade Winds, you were driven hither and thither. You are in smooth water at last, food, and whisky, are running short, and you begin to wonder what on earth, or sea, your longitude is, that is, how much more of the ocean you have to cover. Your chronometer is still ticking away, and you have a note of its 'rate' of loss or gain each day.

The shadow tells you your Local Time is 10 a.m. Your chronometer tells you that Greenwich Mean Time is 2 p.m. (14 hours). You put 10 on the Dial over 14 hours on the Ring: and under 12 (Dial) is 60° West, your longitude - 17° East of Jamaica. You may or may not be able to make the necessary small correction for Equation of Time: but for your purposes you now know sufficiently well whereabouts you are.

On your way home from the Far East you have been carelessly parachuted from an aircraft. You have no idea where you are, but fortunately your Sun Clock is intact. You set it up (details later) with both 12's over your meridian line. The

shadow marches round the morning hours. You rather think you may be South of Tripoli (15° E). Just as the shadow falls on 11 a.m. (on the Dial) you hear the pips on the radio (B.B.C. Overseas Service) which announce that Greenwich Mean Time is 8 a.m. Accordingly you move the Dial to the right till 11.0 (Dial) is over 8 a.m. (Ring). Under 12 appears ADEN 45° East – you are in the wrong desert.

Or, again, you can move the Ring to the left till 8 a.m. (G.M.T.) is under 11 a.m. (L.M.T.), and Aden 45° E will be under 12 on the meridian line.

A crude illustration, but, I think, correct.

Time-finder (Domestic). But Model Two is not a navigational instrument only.

It is also a Time-finder for the home, less 'popular' perhaps than Model One but more scientifically constructed.

In the daytime, when the Sun shines, you have the Universe under your thumb. Your Dial represents your little local world, and wherever the shadow falls that will be your Local Time. But your Ring represents the World: and the two together show your place, and the Sun's place, in the world. When your shadow falls on 10 (Dial) it will also fall on Cairo 10 – 30° (Ring). The Sun is 'over the meridian' of Cairo (or very nearly) so it is noon at Cairo. Wherever the shadow falls on the Ring it is at that place, at that moment, Noon-by-the-Sun. You can thus follow the Sun not only through your own little day (on the Dial) but on the Ring, half round the globe. As he moves on you can see the peoples, in their turns, creeping under the palm-trees, opening the picnic baskets, rushing to restaurants, or ordering pink gins. I find this fun.

You cannot, as with Model One, see at a glance what time it is in New Orleans when it is 3 p.m. at Aden. But there are other advantages. You can now, very simply, make your dial tell any time you like, Greenwich Time, Summer Time, New York Time, Australian Time. The Rule to remember is: If you want to show Greenwich, or any other time, set 12 on the Dial over Greenwich, or any other place desired, on the Ring.

Let us go by stages, with your dial before you. You live, shall we say, at Falmouth, 5° , and 20 minutes, West.

1] You start with 12 on both Ring and Dial over the meridian line. Now the shadow will show, on both, your local Sun Time, which we have seen is at least 20 minutes behind Big Ben, because of the difference of longitude. To get Greenwich Mean Time you must do the drill as described on page 58.

2] But now, as in Model One, but differently, you can eliminate the longitude trouble. You will set your Clock to your own longitude. Move the Ring (*not* the Dial) to the right till 5° West (12h 20m) is over the meridian. This will be its normal position.

Now on your Dial the shadow is still telling your local Sun Time. But on the Ring it is telling Greenwich Sun (or Apparent) Time - 9 on your Dial, for example, but 9.20 on the Ring.

3] But you want to see Greenwich Time on your Dial. So you move it till 12 stands over Greenwich 0. Now on both Dial and Ring the shadow is telling Greenwich Sun Time.

4] Sun Time only - but you want Mean Time. So you adjust your Dial for Equation of Time, as already explained. Another turn and (if you want it) you can have Beastly Summer Time.

If you like you can turn the Ring into Mean Time too (you will have to, if you want to find your longitude). But as a rule, I prefer to leave it on the Sun. Then you can see at a glance the difference between Mean and Sun Time. Also, you can play the little imaginative game I have mentioned. When the shadow falls on 9 hours a.m. 45° you can tell the children: 'The sun is over the meridian of 45° East. It is Noon-by-the-Sun at Aden.'

If anyone doubts this statement you must do the old sum for them again: I am on the meridian of Greenwich. First I set my Clock in its original simplicity with both the 12's on the meridian line. Then on the *Dial* I allow for the Equation of Time which is *minus* 8 minutes. That is, I put 12 on the Dial 8 minutes, or 2 degrees, to the right.

Now imagine an enquiring man at Aden. He knows that it is about to be Noon-by-the-Sun there. He wants to know what will be the Greenwich Mean Time of it.

	h	m	s
Hour Angle of the True Sun	24	0	0
- E	11	52	0
Local Mean Time	12	8	0
Longitude East	3	0	0
G.M.T.	9	8	0

Now, I look at my Clock and I see that when the shadow falls on Aden $9^{\circ} 45'$ on the Ring, it also falls on 9.8 on the Dial which is Greenwich Mean Time. What I told the children was true.

But you are away at Falmouth, and at that moment on *your* Clock the shadow will fall on 8.48 (Dial) and 8.40 (Ring). Move both Dial and Ring 5 degrees to the right till Falmouth is over the meridian, and tomorrow the shadow will fall exactly as it did on mine.

You can play other games, some of them with a practical purpose. I do not say that many will want to play them often, but to be able to play them gives the dialler a delightful sense of command. They illustrate too the capacity of the instrument and, I think, support my claim that, properly developed, that capacity might serve the navigators.

To keep it simple we will say now that you live on the meridian of Greenwich. A rich man who likes sitting in the garden with his Sun Clock handy means to telephone to *New York*. He puts 12 (Dial) over New York (or rather $75^{\circ} 1'$ which means 5 hours) and all day the shadow on the Dial will tell New York Time. On the Ring it will tell Greenwich Time (both Sun and Mean). He can see thus that when it is 4 o'clock in his garden it will be 11 in New York, a time convenient to both ends.

A New Yorker has a Sun Clock too. This is set for his own longitude 75° (Ring) on the meridian line. So, without shifting anything, he can see at a glance the difference between New York Time and Greenwich Time. It is 9 a.m. at New York, the shadow tells him (on the Dial) but the same shadow tells him (on the Ring) that at that time it is 14 hours (or 2 p.m.) in London.

On July 17 he has to make an urgent business call. It must not be too early for a New York office or too late for a London one. He settles for 3 p.m. in London - 10 a.m. in New York. But someone reminds him that the idiot British have Beastly Summer Time in force. Three o'clock in London has now become 4 o'clock. Also today the Sun is 6 minutes slow on the clock.

i] He moves his Ring one hour to the right - 15 hours (London) is now under 9 (N.Y.). He puts the Ring back (to the right) another 6 minutes, for Equation of Time: and now at 8.54 (N.Y.) the shadow will show him on the Ring, that it is 15 hours - 3 p.m. (Beastly Summer Time) in London.

¹ Strictly $74^{\circ} 1' W$.

ii] Or he can do it another way. He moves 12 on the Dial till it is over Greenwich. Now it is telling Greenwich (Sun) Time. He puts 1 there instead and moves it on another 6 minutes. Now the shadow, instead of showing 8.54 (N.Y.) on the Dial will show, at the same point, 3 p.m. (London - B.S.T.).

Lisbon, in Longitude $9^{\circ} 7'$ West, uses Greenwich Time. So the Sun Clock owner puts 9° (Ring) on his meridian line, and 12 (Dial) over Greenwich: and, if he makes the right adjustments for Equation of Time and B.S.T., he is always ready for the 1 o'clock News.

Beirut is in Longitude $35^{\circ} 30'$ East (which means 2 hours and 22 minutes ahead of Greenwich). But Israel keeps time only 2 hours ahead of Greenwich. So if the Beirut citizen wants to be ready for the pearls of Jerusalem Radio he puts his 12 (Dial) over 10 hours 30° E (Ring).

Colombo is in Longitude $80^{\circ} (79^{\circ} 56')$ East - 5 hours and 20 minutes ahead of Greenwich. But the British tea-planter or merchant has similar facilities. He keeps 12 (Dial) over 80° (Ring) and both over the meridian line (that is, when Sun and Clock agree) and the Dial gives him Colombo Time. At 5.20, without doing any sums, he can say: 'Look, it's noon in dear old London.' On Christmas Day he wishes to ring up the old folks at home, and that, he decides, will be a good time. No, 12.30 perhaps, when they have come back from church. That, he sees, will be 6 (Colombo Time).

Or, if he is *very* sentimental, he can put his 12 over Greenwich, and all day long the shadow will be telling British Time.

We all know that *Australian* Time is 10 hours ahead of ours (that is in Queensland, New South Wales, and Victoria - Western Australia is only 8 hours ahead), and the mental arithmetic is often confusing. But, sunshine or no, the Sun Clock makes all clear. Put your 12 (noon) over Sydney ($150^{\circ} 12'$ East). When it is noon at Greenwich, on the Ring, it is 10 p.m. at Sydney on the Dial. When *exactly* does the Test Match start? If the first ball is bowled at Sydney at 11.30 that will be 1.30 a.m. here. If the Sun does shine the shadow will tell Australian Time when the Sun is no longer shining there.

Thinking of you always, I append a list of cities, capes, and places all round the world, with their longitudes, which you may find interesting to mark upon the outer Ring of your Sun Clock. They go West from Greenwich. You will

not have room for all of them; you must make your own choice. Your Sun Clock, apart from anything else, will answer any of those teasing questions: Which is the farther West – Glasgow or Liverpool? Is Gibraltar East or West of Falmouth? Is Cape Horn West or East of New York? You may like to know that Timbuktu is due South of Lyme Regis, that Jamaica is more Westerly than Bermuda or the Bahamas; and that small England covers $7\frac{1}{2}$ degrees of longitude and the British Isles 12 degrees of longitude (Lowestoft $1^{\circ} 46'$ E and Dunmore Head, in Eire, $10^{\circ} 29'$ W).

Merely to make this list has made me realize how cloudy one's knowledge of geography can be. Would you have said offhand that Stockholm was East of Italy – and Copenhagen North of Rome? Nor would I. But they are.

Greenwich	$0^{\circ} 0'$	Ascension Island	$14^{\circ} 21'$ W
Reading	$0^{\circ} 58'$ W	Tenerife	$16^{\circ} 40'$ W
Portsmouth	$1^{\circ} 5'$ W	Madeira	$17^{\circ} 0'$ W
Cowes	$1^{\circ} 18'$ W	Iceland	$22^{\circ} 0'$ W
Manchester	$2^{\circ} 12'$ W	Azores	$29^{\circ} 0'$ W
Bristol	$2^{\circ} 35'$ W	Rio De Janeiro	$43^{\circ} 12'$ W
Timbuktu	$2^{\circ} 55'$ W	St John's, Newfoundland	$52^{\circ} 40'$ W
Lyme Regis	$2^{\circ} 56'$ W	Buenos Aires	$58^{\circ} 20'$ W
Liverpool	$2^{\circ} 58'$ W	Bermuda	$64^{\circ} 50'$ W
Orkney Isles	$3^{\circ} 0'$ W	Cape Horn	$67^{\circ} 14'$ W
Edinburgh	$3^{\circ} 11'$ W	Quebec	$71^{\circ} 12'$ W
Madrid	$3^{\circ} 43'$ W	Valparaiso	$71^{\circ} 40'$ W
Plymouth	$4^{\circ} 7'$ W	Bahamas	$74^{\circ} 0'$ W
Glasgow	$4^{\circ} 15'$ W	New York	$74^{\circ} 1'$ W
Isle of Man	$4^{\circ} 30'$ W	Ottawa	$75^{\circ} 42'$ W
Falmouth	$5^{\circ} 4'$ W	Jamaica	$77^{\circ} 0'$ W
Ushant	$5^{\circ} 10'$ W	Panama Canal	$79^{\circ} 50'$ W
Gibraltar	$5^{\circ} 19'$ W	Cape Kennedy	$80^{\circ} 30'$ W
Land's End	$5^{\circ} 43'$ W	Hudson Bay	$87^{\circ} 0'$ W
St Helena	$5^{\circ} 44'$ W	Chicago	$87^{\circ} 40'$ W
Dublin	$6^{\circ} 16'$ W	New Orleans	$90^{\circ} 1'$ W
Scilly Isles	$6^{\circ} 17'$ W	Mexico City	$99^{\circ} 1'$ W
Casablanca	$7^{\circ} 35'$ W	San Francisco	$122^{\circ} 25'$ W
Lisbon	$9^{\circ} 7'$ W	Vancouver Island	$126^{\circ} 0'$ W
Finisterre	$9^{\circ} 15'$ W	Klondike	$139^{\circ} 20'$ W
Fastnet Light	$9^{\circ} 36'$ W	Christmas Island	$157^{\circ} 30'$ W
Bantry Bay	$9^{\circ} 45'$ W	Honolulu	$157^{\circ} 51'$ W
Achill Island, Mayo	$10^{\circ} 0'$ W	Fiji	$179^{\circ} 0'$ E
Dunmore Head	$10^{\circ} 29'$ W	Wellington (N.Z.)	$174^{\circ} 47'$ E
Tristan Da Cunha	$12^{\circ} 0'$ W	Brisbane	$150^{\circ} 30'$ E

Sydney	150° 12' E	Cairo	31° 15' E
Melbourne	145° 2' E	Durban	31° 1' E
Tokyo	138° 45' E	Leningrad	30° 15' E
Adelaide	138° 35' E	Helsinki	24° 57' E
Vladivostok	131° 53' E	Athens	23° 45' E
Formosa	121° 0' E	Corfu	19° 56' E
Fremantle	115° 45' E	Dubrovnik	18° 9' E
Hong Kong	114° 12' E	Stockholm	18° 5' E
Singapore	103° 51' E	Vienna	16° 23' E
Lhasa	91° 5' E	Naples	16° 14' E
Calcutta	88° 24' E	Messina	15° 34' E
Everest	86° 58' E	Malta	14° 25' E
Colombo	79° 56' E	Berlin	13° 25' E
Bombay	72° 54' E	Tripoli	13° 15' E
Mauritius	57° 0' E	Rome	12° 28' E
Socotra	50° 0' E	Copenhagen	12° 5' E
Aden	45° 4' E	Tunis	10° 10' E
Baghdad	44° 27' E	Elba	10° 10' E
Mecca	39° 54' E	Oslo	10° 0' E
Addis Ababa	38° 44' E	Marseilles	5° 22' E
Moscow	37° 37' E	Bordeaux	5° 9' E
Damascus	36° 18' E	Amsterdam	4° 55' E
Beirut	35° 30' E	Brussels	4° 22' E
Jerusalem	35° 13' E	Dunkirk	2° 22' E
Cyprus	33° 0' E	Paris	2° 20' E
Khartoum	32° 35' E	Barcelona	2° 10' E
Suez	32° 33' E	Havre	0° 6' E

Summer and Winter. There is one snag which I have not yet revealed. It will not affect the ordinary dialler in England: but the serious skiaphilist has still another stage to go.

The Sage of 1820 says:

As the Sun only illumines the upper surface of an equinoctial plane while he is in our hemisphere, on the northern side of the equator, an upper equinoctial dial will only shew the hour during the spring and summer season. . . . To have an equinoctial dial, therefore, that shall serve all the year round the upper and lower must be joined together; that is, it must be drawn on each side of the plane.

More simply, after September 23, when the Sun goes below the Equator, he cannot, naturally, get over the top of your equatorial dial, so no shadow is thrown on it till he comes North again on March 20. But if you wish to go on using it

in winter you can draw another Dial (and Ring) on the lower side. But remember, if you do, that now the morning hours must be on the *left*, and the afternoon hours on the right. On the Ring, too, you must mark both hours and longitude the other way round.

The Sage, having commended 'the Equinoctial' in the glowing terms I quoted at the beginning, says: '... but the necessity of drawing it double prevents it being much in use'.

This is defeatist doctrine. At this moment, at 11 o'clock on a wintry morning, December 15, I have a 'lower' equatorial telling very good time. True, it is not quite so satisfactory. If you keep the thing at its ordinary level you have to stoop and peer. But put it in some elevated position where you can look up to it and all is well. Much depends on the latitude you are in. The further South you go the greater is your co-latitude and the steeper, therefore, the angle at which your dial will stand. In latitude 30° the angle will be 60° , making inspection easy. Nearer the Equator the dial will be nearly perpendicular. But as you go North the angle will diminish and at last make your lower too difficult, though no doubt the shadow will be there. The latitude of Stockholm is $59^{\circ} 20'$ North, so your lower would be at an angle of 30° .

Larger Clocks. So much for Models One and Two – the small 'portable' Sun Clocks, for the schoolboy, humble house-husband, or retired mariner. I have bigger and better plans for those who could afford professional construction.

Model Three

1] *Private.* For the country-house garden, the school, the hospital, the golf club, the sailing club, the forecourt of opulent firms or factories I see more stately, fixed affairs in stone. I unveiled not long ago a strange symbolic obelisk for a famous company, and I was glad to do so; for it was a gesture from Industry to Art and good money for the sculptor. But I thought how much more useful, and decorative, one of my Sun Clocks would have been, artistically embellished by the same hand. Instead of that bust or portrait of dear old Foskery, so long the President of the Bursledon Golf Club, there should be a Memorial Sun Clock at the first tee. The members, while queuing to drive, could improve their geography and astronomy. For the young things at school or the sailing club it would be a continual education: for the country-house party a fount of conversation.

This Model should be marked, I think, on the lines of Model One. It would be permanently set for the Latitude and Longitude of the place, so the constructional problems would be small. If it were desired to have a 'lower' dial, for the winter, the Clock should be raised on a stone base. Sculptured nymphs or naiads could support the Clock - provided that they did not keep the Sun from the 'lower' Dial. It would be possible, with care, to provide for both. At the Golf Club, the back of the Clock might be made into a shelter from the rain. It might be better to have a vertical - or polar - dial on the South side. This would act all the year, give variety, and serve to support the Sun Clock (pages 125, 127). The style should be hinged, so that a waterproof cover, rolled at the top, could come down and protect the Clock at night or in wet weather.

2] *Public.* Local Authorities too, make generous gestures to Art, like to commemorate past worthies and to impress their citizens and other Councils. Here and there a Council Sun Clock might be a good notion: and great will be the public interest in the first to be erected. These public ones should be bigger still. The names of the places must be readable at a distance - an important point. The public Clock should be a thorough thing and must either have a 'lower' dial which can be read in the occasional Sun of winter, or, as suggested, a vertical on the South side. So the Clock must be well above the level of the Park. This too should make it easier to defend the Clock against small boys and other rampagers. On that problem the Councillors will know best, but I shyly mention again my surrounding moat - with or without barbed wire.

The park-keeper will be presented with a Nautical Almanac by the Council, and will make the necessary adjustments each day, or, sometimes, every other day. If the thing is too big to move by hand there will be a crank and cogs at the back.

One Piece - or Two?

A problem for the creators of a Public Sun Clock will be: 'Which of its powers to use - and how?' The Borough Council is not likely to want to find its longitude: so that can be forgotten. Its main purpose is to induce the Sun to give the rate-payers 'The right time', meaning, (a) Mean Time, and (b) alas, British Summer Time. This is easily arranged by moving the Dial. The greatest Equation of Time from April to August is 6 minutes - which means, in an Equatorial, $1\frac{1}{2}$ degrees

and in a Vertical just under 1 degree. Summer Time would require, twice in the year, a bigger adjustment through 15 degrees. If the Curator could not manage this manually crank and cogs could, no doubt, be employed.

But the Sun Clock is not only a time-keeper. It is intended to be a source of interest and instruction, whether the Sun shines or not, through its power of showing comparative times all over the world and giving the observer a clear notion of his place in the world: 'Oh look, when it's 12 o'clock in London it's 10 p.m. in Sydney.' This remains however much the Dial is moved. But if the Dial were turned to Mean Time and the Ring left telling Sun Time, the picture would not be so clear. It would be better then to adjust Dial and Ring for Equation of Time together.

There remains the question of Summer Time. It would be possible to move the Dial on 1 hour and leave the Ring as it is. Little would be gained by this. The only moment when Summer Time was confronted with Greenwich Time (in this model) would be at noon: but the uninstructed might be led to look for it elsewhere.

The conclusion is, then, that Ring and Dial had better move together always: and therefore, for a public place, they should be made in one piece, which would be an economy.

But if such a Clock were erected at Greenwich where lectures might be given, and e.g. the method of finding the longitude were shown, Ring and Dial should be separate and able to move independently.

Dimensions. Size must depend on the scene, the expense – and the shadow. Long shadows grow woolly at the ends. Where high accuracy is not required, this is no great matter, perhaps, but it must be remembered. The following figures are intended to illustrate the problems and stimulate discussion.

(1) *For a Park*

Wishing to make things easy for the man who has to mark the instrument I have tried to calculate round figures for the *circumference* of the Dials and therefore for the hour-divisions. There are after all only two diameters to be marked, but 24 hour-lines, and as many minutes and degrees as possible: but someone must check my π work.

I suggest, then:

DIAL Diameter 7.644 feet - Radius 3.822 feet (and length of shadow)

This gives, I think, a circumference of 24 feet

This would mean 1 foot or 12 inches to every hour
4 inches for 20 minutes or 5 degrees
1 inch - 5 minutes

RING Diameter 9.54 feet - Radius 4.77 feet - Circumference 30 feet

This would give 1.25 feet or 15 inches to every hour
1 inch to every degree
1 inch for 4 minutes

For protection, and to provide convenient viewing, the Clock should be mounted on a stone base, say, 3 feet high. The height of the instrument from the base would be 8 feet, or 11 feet in all (see Plan). Height of style 2 feet.

(2) *For a Country House, Hospital, Golf Club, etc.*

A simple course would be to divide the measurements above by 2. This would give:

DIAL Diameter 3.822 feet - Radius 1.911 feet - Circumference 12 feet
6 inches to every hour
2 inches to every 20 minutes

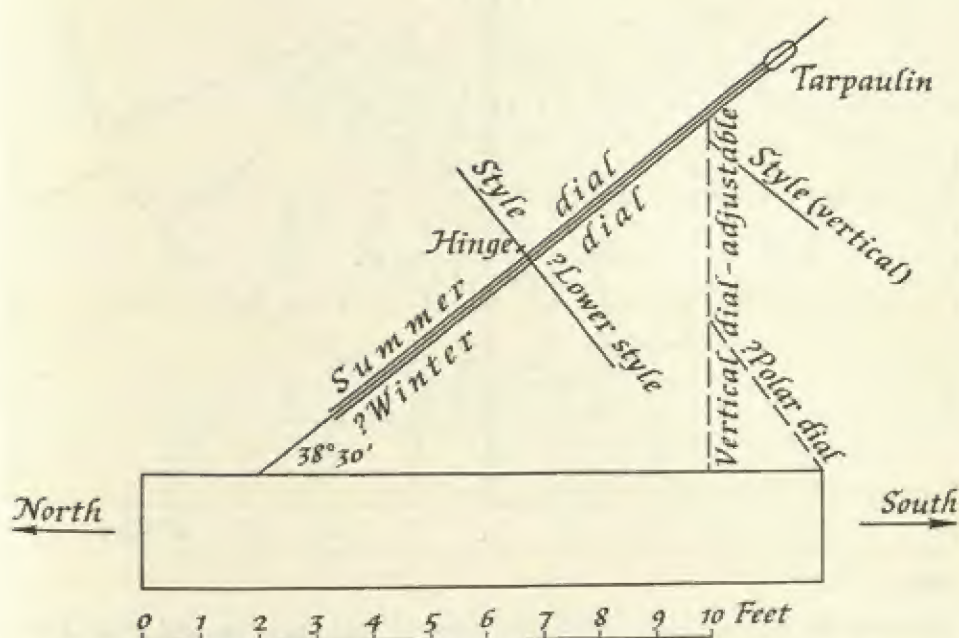
RING Diameter 4.77 feet - Radius 2.385 feet - Circumference 15 feet
 $7\frac{1}{2}$ inches to 1 hour
1 inch to 2 degrees
Height of style 1 foot

I have made rough plans for:

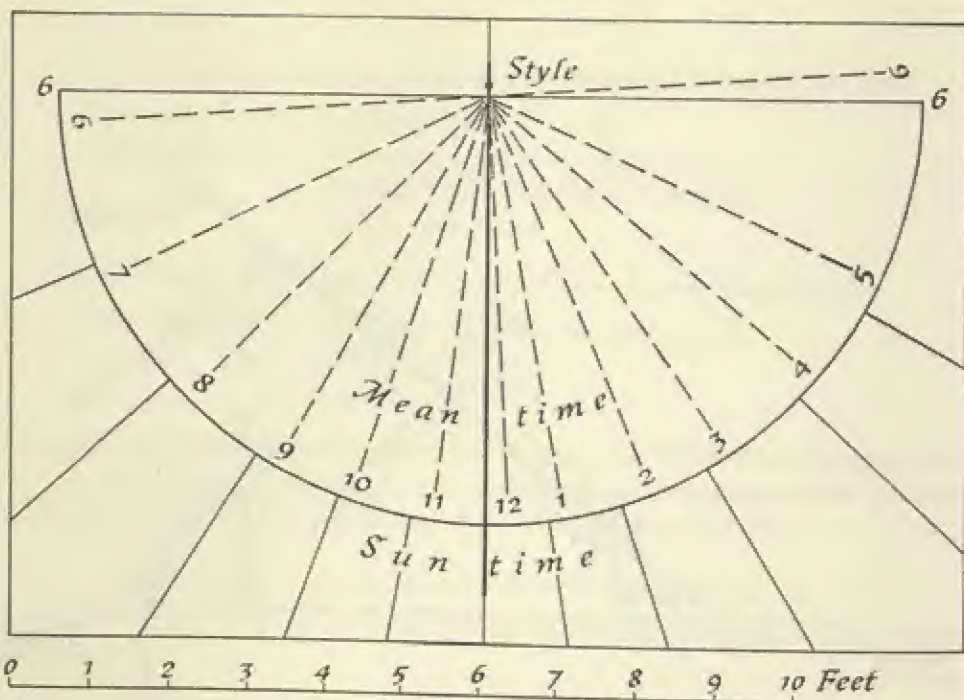
a] a Sun Clock, backed and supported, on the South side, by a Vertical Adjustable Dial.

b] A Sun Clock, backed by a Polar Dial, which would meet the Sun Clock at a right angle.

c] A Sun Clock, backed by a Vertical and a Polar Dial (this is a humble offering to Greenwich).



PUBLIC SUN CLOCK Lat. $51^{\circ} 30'$ (ELEVATION). Note: Instead of the 'Lower' Equatorial Dial, for the winter, there might be (a) a Polar Dial telling Sun Time or (b) an Adjustable Vertical telling Sun Time and Mean Time. Either of these would act all the year and would help to support the Equatorial. Thus the whole instrument would give three times - Sun and Mean Time (Vertical) and Summer Time (Sun Clock).



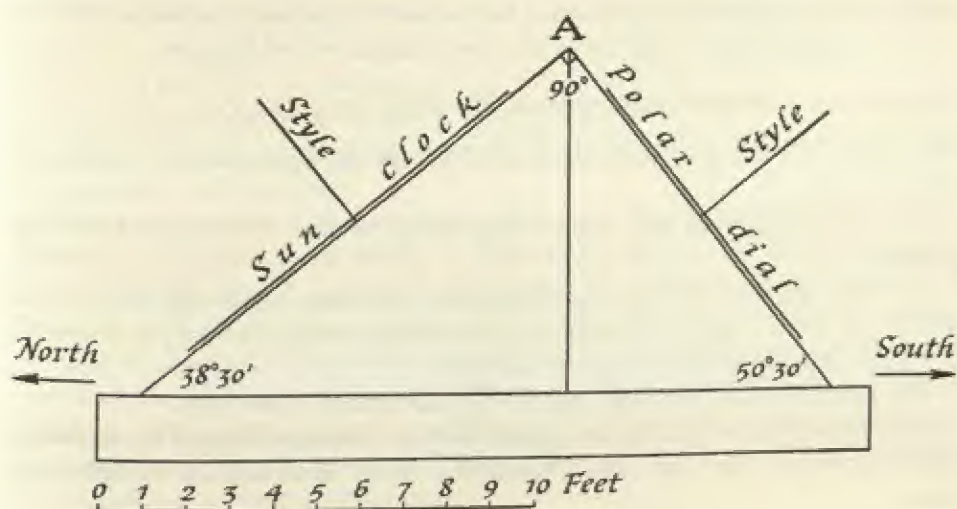
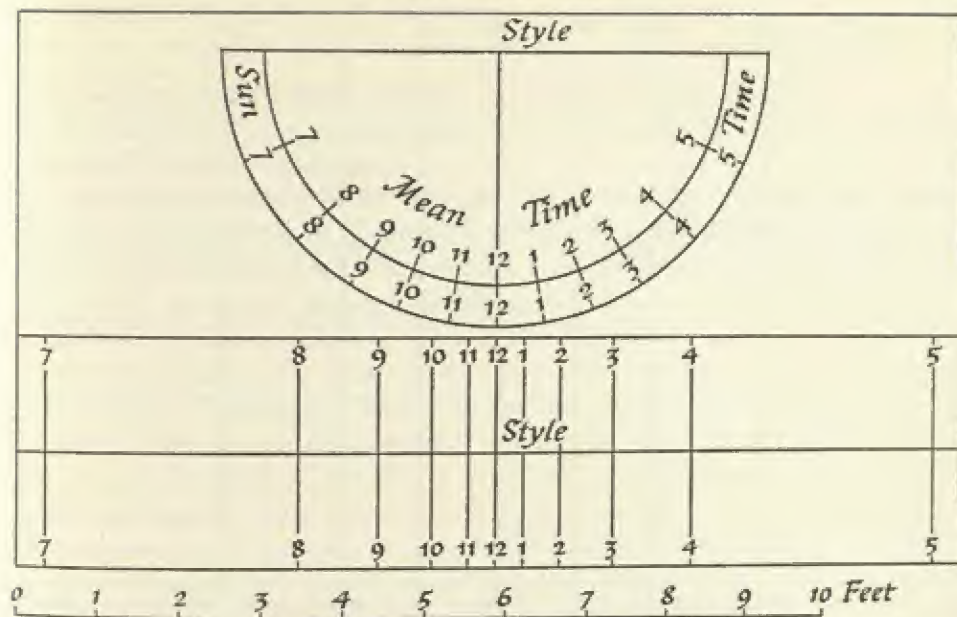
SOUTH SIDE OF SUN CLOCK Adjustable Vertical - showing Sun and Mean Time. November 10 - Equation of Time at Noon - plus 16 minutes 3 seconds. The Sun is 16 minutes ahead. But the dial has been adjusted, and when the shadow falls on the meridian line - 12 - the dial says 11.44.

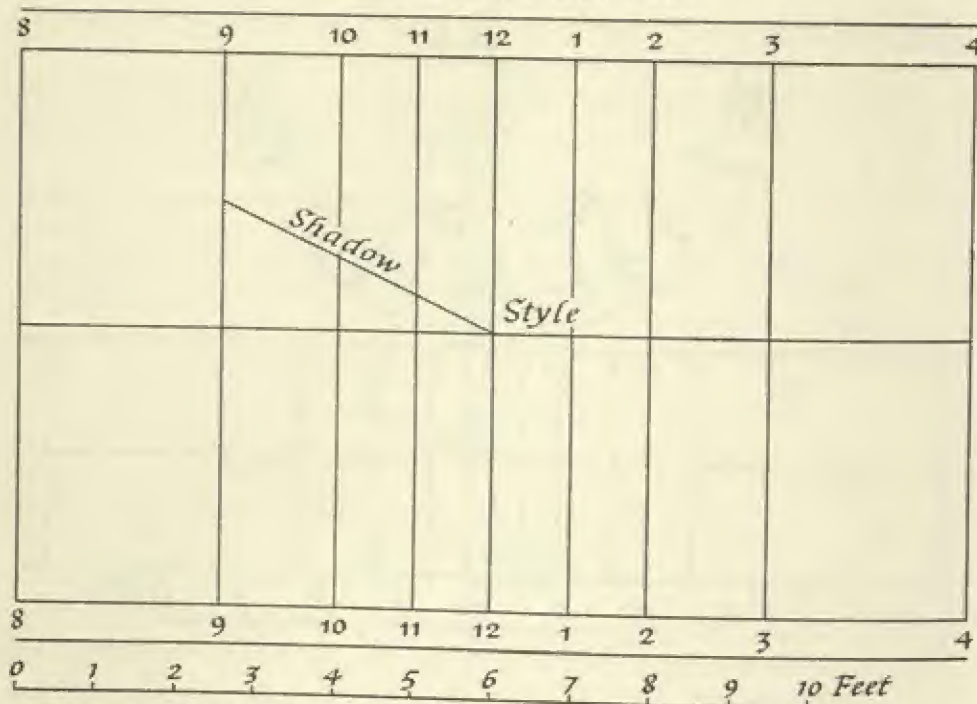
top right

ALTERNATIVE SOUTH SIDE FOR SUN CLOCK - above, an adjustable Vertical, below, a Polar Dial. Dimensions - Polar Dial: 8 a.m. to 4 p.m. 5 feet, overall 12 feet, height of style 1 foot 6 inches. Vertical: radius 3 feet 6 inches.

bottom right

PLAN (ELEVATION) South side for Sun Clock - Polar Dial. Dimensions: length of pedestal 18 feet; height of A from pedestal 8 feet. Sun Clock - Dial: Diameter 7'6.44 feet; Ring: Diameter 9'5.4 feet - Width of Clock 20 feet.





POLAR DIAL to go with Sun Clock - South side. Dimensions: width of Dial 12 feet, height 7 feet (overall 8 feet), height of style $3\frac{1}{2}$ feet.

Notice for the pedestal of a public SUN CLOCK

This Sun Clock is a modern development of the ancient Equatorial Dial which told Sun Time only.

The Clock is adjustable and is now telling British Summer Time on the inner ring of figures.

The outer ring does not show the present time anywhere, but the difference in time between the places named on the inner ring. For example, when it is 1 p.m. at Greenwich it is 8 a.m. at New York and 6 p.m. at Bombay.

The Vertical Dial on the South side is telling Greenwich Mean Time.

From September 23 when the Sun passes below the Equator till March 21 no shadow will be thrown on this Clock. The Vertical Dial on the South side acts throughout the year.

Orientation

Here are some special hints about the orientation of an Equatorial.

1] If you descend to a compass stick it on to the platform North of the dial. (But see 'Compass' – page 47.)

2] Under the overhang of the dial (on the South side) you can have another dial of a different kind, an Elliptical or a Polar. If the two agree about the time it must be right, and you must be oriented. I am not sure that a horizontal would not qualify for use at home. But if your No. 2 is a Polar your instrument is 'universal' – for both dials will work in any latitude.

3] For the Equatorial I have a new and original 'orienter' of my own which calls in aid the Declination. This I call the Second Style, but, in fact, so far, it is merely a silken thread. It passes from a point just above the top of the Ring to the main style, where it is made fast *at the angle of the Declination*. (I measure this with a protractor.) This thread throws a shadow which, when the instrument is properly set, meets the main or time shadow at the rim of the Ring. If all is well these two shadows will remain together there, touching at the rim, all day, which is impressive. They will tangle, of course, as Noon approaches, and at Noon they fall together on the meridian line. (As the declination rises or falls small adjustments may be needed in the afternoon.)

Now these two shadows will not do this engaging double turn if there is anything wrong. If your latitude setting is not right they will climb into the interior of the Dial, or separate and go off it altogether. Least of all will they perform if the instrument is not properly oriented. Move it by a centimetre away from the South and the two shadows will separate – or cross. So the instrument is 'self-southing'.

The beauty of this is that you can orient your Sun Clock instantly, without looking at a compass, local marks, or other aids. I took a Sun Clock with me on one of our Thames Conservancy inspections. In certain parts of the river the twists are so sudden, severe, and persistent that without a compass one can lose all sense of direction. I found that with my two converging shadows I could keep my clock aimed South continuously. I have done this too on a yacht in the Mediterranean. The device, then, is a great comfort to the earnest dialler who has got his instrument beautifully adjusted but is then driven from his favourite table by tea-trays or women potting plants.

It is quite a business, I confess, maintaining the thread and accurately altering the angle. I did imagine a 'declination gauge' at the top of the Ring, and a more robust 'second style'. But a kindly expert has got us out of all this. The second shadow was new to him: but he remarked that the same effect could be achieved by having a 'runner' on the main style and marking the declination on the style. This is correct. By a 'runner' is meant some small object that can slide up and down the style but will stay steady when set to the declination of the day. (A bit of rubber with a hole in it will do - but you should do better.) The shadow of the 'runner' should then fall near the edge of the circumference of the *Dial*, and march round it all day. If you turn the Clock a fraction away from the South the shadow will retreat up to Dial-face or go off over the Ring. So it is successfully self-southing, and it is much less trouble. But it is not, visually, so satisfactory. I like to see my two shadows dutifully converging. Also, when they make one shadow at noon this is a great confirmation that it *is* noon, and all is well. You must try both methods.

Graduation

But how do we 'graduate' the style - that is, mark it for the declination? I have just worked this out for myself.

a] You can, of course, do this geometrically. Draw a little right-angled triangle to scale, with the radius of your Dial as the *base* - say 3 inches. At one end will be a perpendicular line, the style. From the other end draw a line at an angle of say 20° , and measure the height at which it hits the perpendicular. That will be your mark for a declination of 20° , and you can do all the other angles likewise, from 1° to 23° .

b] Or you can do it by trigonometry.

The formula (I *think*) is

$$h = \tan A \times d$$

A is your angle (20°), *d* is your base - the radius of your Dial - and *h* is the height of the point on the style where you will mark 20° - e.g.

$$\log \tan 20^\circ = 9.56107$$

$$\log 3 \text{ inches} = 0.47712$$

$$10.03819 = 1.09 \text{ inches}$$

If you would prefer to have the shadow of your runner on the edge of the Ring (which I think is better) the base of your triangle (*d*) must be the radius of the Ring.

For the benefit of the beginner who is using a 6-inch diameter Dial I have worked out all the angles.

<i>Declination</i>	<i>Height of marking on the style (in inches)</i>
1°	0.05
2°	0.10
3°	0.16
4°	0.21
5°	0.26
6°	0.31
7°	0.37
8°	0.42
9°	0.47
10°	0.53
11°	0.58
12°	0.64
13°	0.69
14°	0.75
15°	0.80
16°	0.86
17°	0.92
18°	0.97
19°	1.03
20°	1.09
21°	1.15
22°	1.21
23°	1.27

As usual, the table gives a useful general picture. The differences between two degrees of Declination are always 0.05 or 0.06, so you will not feel obliged to mark all of them. Every other one should be enough – or even less.

You can use these markings, of course, if you prefer to keep the silken thread. Make little slits in your style. Make a little bowline at one end of your thread (not too easy), and pop it over the style. Pass the other end through a little hole in your dial-‘plane’ and tie it to some small but substantial object. The weight will keep the thread taut in its appropriate slit. But, I admit, the ‘runner’ is much less trouble.

Southern Hemisphere

I have not forgotten — as all other writers do — those who live South of the Equator. In the junior hemisphere the Sun is North at Noon. In these conditions turn the Sun Clock through 180° so that the Top is towards the North. Then rotate the Ring — but not the Dial — till Greenwich 0° is over the meridian line at the top and 180° is over it at the bottom. The Clock is then set for Fiji Time and — I *think* — will serve the same purpose. The Sydney citizen (indeed, most Australians) will set his longitude (150° E) at the bottom and 12 over it. But the Sun, though he is in the North, will still be coming from the East, so since the dial is now reversed the morning shadows will fall on the afternoon hours (if you made your dial in London). If you are a thorough man who has fitted a 'lower' as well as an 'upper' dial the solution is simple — you transpose the two. But I expect the British Modern Sun Clocks Company will make a special model for South of the Line.

ELLIPTICAL DIAL

Late in the *Encyclopaedia Britannica* article on DIAL you may read:

The Analemmatic Sundial differs from other portable sundials in that it can be set for finding the time without a compass. It includes two dials, an ordinary horizontal dial and an *elliptical dial* with a perpendicular gnomon which is set to the declination on a scale of months and days engraved along the minor axis of the ellipse.

In use the two styles cast two shadows on their respective hour-scales. The instrument is then turned about until the two readings agree: when this happens the hour indicated is the correct time and the central line is true north and south.

Two pages earlier there is a picture of a 'portable analemmatic sundial of the 18th century'. But no hint is offered on how you construct the thing.

'Analemmatic' — this is a fine example of the way they bully us with long and pompous words, which do not mean very much; and here is a tale to encourage the amateur.

When I first saw 'analemmatic' I shied away; I had not the guns for it, I thought. But I went back, tackled and tamed the monster. In my great Oxford English Dictionary I found that originally the Latin word *analemma* (Greek root 'take up')

meant simply the *pedestal* of a sundial – hence the sundial itself. That is how scientific it is! It has collected other odd meanings including ‘a special sort of gnomon’, and ‘the scale of the sun’s daily declination drawn from tropic to tropic on artificial terrestrial globes’. So we must not let it frighten us. But I still do not know why it is the name of this particular form of sundial. But there it is, a Double Dial (and I shall call it so) cleverly oriented by telling the same time in two different ways.

I have never ‘been shipmates’ with an elliptical dial, and the *Encyclopaedia Britannica* is far from clear: ‘... an elliptical dial with a perpendicular gnomon which is set to the declination on a scale of months and days engraved on the minor axis’.

I could find nothing about it in any of my books, except a picture of a ‘lyre-shaped’ horizontal analemmatic dial dated 1763. It looks a beautiful thing, but not the slightest explanation was given of the way it was constructed, or how it was worked.

The thing attracted me for two reasons. One, it was proudly independent of the compass, and two, it seemed to be an example of the impossible, a perpendicular on a horizontal plane (or, to put it plainly, a stick in the sand) telling the time correctly – and permanently.

An antiquity surely to be revived. I went after it with the zest of a poacher.

I wrote to my friend at the National Maritime Museum, but for once got no reply. I thought he had had enough of me: so I decided to try myself.

It is rather like cooking. *First take an ellipse.* You probably know the string trick for making an ellipse. More elaborate methods are given in the *Encyclopaedia Britannica*, but it works very well and can be made to measure.

An ellipse is a circle somebody has trodden on. It is, I think, the path pursued by the Earth round the Sun.

First, decide how long your ellipse is to be – say 6 inches. Then draw *AOB* 6 inches long – this is the ‘major axis’. Half this (3 inches) is your Radius. Through *O* the centre draw another line at right angles to the first. This is your ‘minor axis’, and will be *COD*: but we have not yet fixed the position of *C*. The line *CO* (I owe this information to Captain Mark Taylor R.N.) must be equal to your Radius \times the sine of your Latitude. Thus, in Hammersmith:

$$\begin{aligned}\log 3 &= 0.47712 \\ \log \sin \text{Latitude} &= 9.89354 \\ \hline 10.37066 &= 2.34 \text{ inches (this is your 'minor' radius)}\end{aligned}$$

Now take your compasses or dividers and set them at the *major* radius (3 inches) and from *C* mark two points, *F* and *F'*, on the major axis.

F and *F'* are your focal points. Plant two drawing-pins firmly in them (firmly — they are sure to fly out), put another at *C*, and find a piece of string.

Draw your string taut round *C*, *F*, and *F'*, and knot it, a nice reef-knot, if you can. Push the knot out of the way on the South side, take the pin out of *C*, put your pencil-point there instead, and, pressing strongly against the string, draw the upper or North side of your ellipse. The pencil will pass, magically, through *A* and *B*. Draw the South side in the same way, if you wish to be thorough. Here you may well say: 'Why an ellipse?' This is a question too deep for me: but after some ignorant doubting I am persuaded that both the shape and the proportions of this dial are important. You may be tempted to put *C* farther out than you have been told and have a fatter ellipse. Don't. It will look just as well, but it will not always work so well.

We have our ellipse, then, with the minor axis pointing North. What next? How to mark it? I had no idea.

My kind friend at Greenwich sent me several pages (photostats) from that learned Encyclopaedia of 1820 — with illustrations. Here at last were full and detailed instructions: but if I had seen them before my humble efforts would never have been begun.

Combined hour-arc and azimuth dials

(a) Analemmatic

In 1698 Thomas Tuttel's *Description and Use of a New Contrived Elliptical Double Dial* was published. This work describes the instrument now known as the analemmatic dial [excuse a smile], an instrument which includes both an hour-arc and an azimuth dial. [An 'azimuth dial' is a dial where the *bearing*, or direction, of the Sun is the thing that matters.]

The hour-arc dial is an ordinary horizontal dial with the usual style. The azimuth dial is an orthographic projection of the equinoctial [the equator] on the horizontal plane. The hour-ring in this projection is elliptical [why?] with the 12 o'clock line in the minor axis. There is a declination-scale on this axis, with a movable vertical index. The dial is, in fact, a projection of the universal ring dial.

The 12 o'clock lines of the two dials are parallel and in some cases coincident, one dial being superimposed on the other. Both dials will give the correct time if their meridian lines are correctly orientated. If the meridian lines are directed towards the sun, both dials give the time as 12 o'clock, since both indices are in the same vertical plane. But if the instrument is placed in any other position then owing to *the different nature of the dials* they will record different times. If then the instrument is placed horizontally in the sun and turned until both dials give the same reading that reading will be the correct time. The dial is thus self-orienting.

Elsewhere there is a page of instruction and an elaborate diagram which looks like a chart of the human inside. Three circles (including one called 'the Little Zodiac'), the Earth's axis, the equator, the latitude, the co-latitude, are drawn. Each circle is divided into arcs of 15° . Perpendiculars are dropped and parallel cross-lines drawn from the ends of the arcs till the thing looks like a maze. Then you join up the outer junctions of the perpendiculars and the parallels to make your 'Ellipsis'.

All this is to be done 'upon a very even, smooth piece of brass'; and when you have pricked down the hour-points and all is prepared you 'transfer the Hour-points' and the Ellipsis 'to another Brass Plate'.

Spacious days – and skilled performers! Those who would see, or do, such fine work must visit the National Maritime Museum. The ordinary amateur will do better with the string trick.

I did not feel equal to such high exertions myself: and I still did not know any simpler way (a) to mark the hour-points or (b) to 'set the instrument to the declination'.

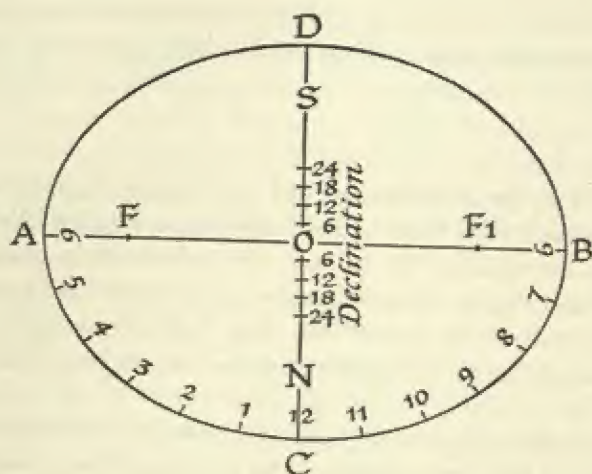
a] My trigonometry is shadowy, as I have hinted, but this tale will show you what grim determination can do. I tried inventing formulae a little different from the ones I knew. I cast about like a hopeful fisherman and at last a formula popped up that seemed to fit the hour-points in the Greenwich picture. Here it is – and I hope it will be known in shadow history as the Herbert Formula (Two):

$$\log \tan H = \log \tan h \text{ minus } \log \sin \text{ Latitude}$$

Why *minus*? you may ask. God knows. But the Horizontal formula, you may remember, is:

$$\log \tan H = \log \tan h \text{ plus } \log \sin \text{ Latitude}$$

and I chose, by chance, a happy variation.



ROUGH ELLIPTICAL DIAL

The hours are marked according to Formula Two
 $\log \tan H = \log \tan h \text{ minus } \log \sin \text{ Latitude}$

Long afterwards Captain Mark Taylor R.N. told me of a more respectable formula:

$$\log \tan H = \log \tan h + \log \operatorname{cosec} \text{ Latitude}$$

Angle for 2 o'clock:

$$\begin{array}{rcl} \log \tan 30^\circ & = & 9.76144 \\ + \log \operatorname{cosec} 51^\circ 30' & = & 10.10646 \\ \hline \log \tan H & = & 9.86790 = 36^\circ 25' \end{array}$$

But the Herbert Formula gets there too:

$$\begin{array}{rcl} \log \tan 30^\circ & = & 9.76144 \\ - \log \sin 51^\circ 30' & = & 9.89354 \\ \hline \log \tan H & & 9.86790 = 36^\circ 25' \end{array}$$

I wish that I understood more of the magic of trigonometry.

b] 'Setting for the declination' too can be done without the laborious drawing prescribed by the Sage of Greenwich. This is the only dial I know in which the 'style' moves from place to place. This is because it is an 'azimuth' or bearing dial: it is governed by the 'bearing' or direction of the Sun which is not the same at, say, 4 p.m. in June as it is at 4 p.m. in March or December. We have been taught to think of the 'style' of a horizontal or vertical as if it were the axis of the Earth. We must now (I think) think of the major axis of your elliptical as the Equator, and your style as the Sun passing North or South across it. At the Equinoxes, in March and September, when the Sun is over the Equator and the declination is 0° , you will plant your needle at 0, and the shadow will faithfully fall on 4 at 4-by-the-Sun. But if you leave the needle there in June, when the Sun has travelled 23° to the North, the shadow will fall far behind 4 – and far ahead in December. So we must move our needle up or down the minor axis, according to the Declination. But how do we mark the Declination? My books did not explain, and I had to devise a rough arrangement of my own. But I am now indebted to Captain Mark Taylor for this precise formula. The distance (D) of each declination marking from 0 must equal the *major* radius multiplied by the Tangent of the Declination and the Cosine of the Latitude. So for a Radius of 3 inches and a Declination of 15° the Hammersmith answer is:

$$\begin{array}{rcl} \log 3 & = & 0.47712 \\ \log \tan \text{Dec. } 15^\circ & = & 9.42805 \\ \log \cos \text{Lat. } 51^\circ 30' & = & 9.79415 \\ \hline \log D & & 9.69932 = 0.5 \text{ inch} \end{array}$$

You can thus prick off, say, every 3 degrees of declination. Or you can content yourself with marking the months and the dates when the Sun enters the various Signs of the Zodiac. I have never myself been one of the Friends of the Zodiac,

and cannot remember the mystic 'Signs': but you can mark the months without them - the summer months North of the major axis. The smart thing is to have a 'cursor' carrying the style and moving in a groove up and down the minor axis.

A Double?

In my early industrious but ignorant days, by the way, I planted my needle on the North side - which was the wrong side, for the declination was South. I drew an ellipse in black, did some 'trial and error' markings and devised a Formula (One) which seemed to fit them. When Formula Two came up, and the other secrets, I drew another ellipse in red but left the black, or wrong, one in action: and there they were, for a time at least, both telling the time correctly. This must be the simplest looking sundial in the world: a 6-inch circle of hardboard, painted white: four lines drawn upon it - the meridian line, the East-West line, and the top half of two ellipses. Standing up - two needles.

I am not betting on this strange 'Double'. I do not even dare to print Formula One. But better men may care to give it attention. After all, a Double Elliptical, with one of the styles on the wrong side of the major axis, would be a world record. Would it count, if a steady performer, as a 'self-southing' instrument? I suppose not. It does not consist of 'two dials of different natures'. But it would be amusing and reassuring. Go to it, skialogists!

Lastly, I imagine sometimes a very large and elegant Elliptical for country houses. The hour-points would be picked out in an elliptical flower-bed, and each hour would have a scale of 4 degrees each way so that Mean Time could be shown. The shadow would be a little short at noon when the sun was highest, but on Midsummer Day, when in London the altitude is 62° , a 10-foot pole would throw a shadow $3\frac{1}{2}$ feet long down the meridian line. When the altitude was 45° (early August) the shadow would be $10\frac{1}{2}$ feet long. So I see an ellipse 20 feet wide by 30 feet long. The pole would travel on an underground carriage cleverly protected from the rain, and it would be the joyful duty of the master of the house (or the butler) to shift it from time to time to the appropriate degree. This would be much simpler than my giant horizontal, where a certain angle must be maintained. The first man to put up a Large Elliptical will have done something never done before.¹

¹ But no. I am told that one exists in a churchyard in the South of France.

Another fancy, less expensive. So far we have talked in terms of the style being moved to fit the declination. But, on occasion, might it not be the ellipse – or rather the hour-points – which moved? That great mast at the National Maritime Museum, and others like it at Naval Barracks and Navigational Schools, look very fine and are useful for exposing the ensign and the flags, but for nothing else. Could it not also become the majestic style of a Large Elliptical? Eight ellipses would be marked on the ground – one for every 3 degrees of declination with the hour-points marked on each. There might also be an inner circle marked with equal hour-divisions. This would show the student how wrong the normal 'stick-in-the-sand' can be.

Let us see how the formula works out for other latitudes.

$$\text{Log tan } H = \text{log tan } h \text{ minus log sin Latitude}$$

Latitude	11 and 1	10 and 2	9 and 3	8 and 4	7 and 5
5°	71° 59'	81° 25'	85° 1'	87° 6'	88° 39'
10°	57° 3'	73° 15'	80° 9'	84° 16'	87° 20'
20°	38° 4 $\frac{1}{2}$ '	59° 21'	71° 5'	78° 50'	84° 45'
30°	28° 11'	49° 8'	63° 26'	73° 54'	82° 22'
40°	22° 37 $\frac{1}{2}$ '	41° 56'	57° 16'	69° 38'	80° 13'
50°	19° 16 $\frac{1}{2}$ '	37° 0'	52° 32'	66° 8'	78° 24'
55°	18° 6'	35° 10'	50° 40'	64° 41'	77° 37'
60°	17° 11 $\frac{1}{2}$ '	33° 41'	49° 6'	63° 26'	76° 56'
70°	15° 55'	31° 34'	46° 45'	61° 31'	75° 52'
80°	15° 13'	30° 23'	45° 26'	60° 22'	75° 13'

Don't be alarmed. You understand this just as well as I do. It is an interesting pattern, is it not? The declination in every case is assumed to be the same: but see what a difference is caused by the latitude. You may consider that near the Equator (5° North) an Elliptical Dial will be strange and unsatisfactory – for there are only 16 degrees between Hour 1 and Hour 5. But then the same is true of a Horizontal Dial – though the angle-pattern is completely different. See:

Latitude 5°	Horizontal	Elliptical
Hour 1 and 11	1° 40'	71° 59'
Hour 7 and 5	18° 1'	88° 39'
	16° 21'	16° 40'

Moral – if you are travelling use the Equatorial where the hour-divisions are equal. For British latitudes, you will see, the Elliptical angles are reasonable

enough; and for most of North America (New York is in latitude $40^{\circ} 43'$ North). The farther North you go the better the Elliptical behaves. In 80° North the hour-divisions are practically equal.

'Modernizing' the Elliptical

I have given much thought to 'modernizing' this ancient dial.

1] To get Mean Time out of it the method is to have a second 'side-stepping' style, on the correct declination line - that is, the same distance from the major axis as your style No. 1. How far to put it from the meridian line can be worked out, no doubt. But the simplest thing is to remember that at Noon-by-the-Sun the shadow will fall on the G.M.T. of Noon-by-the-Sun and plant your needle accordingly. In the same way I can even, between 10 and 4, get Summer Time.

This is sometimes a frustrating exercise. The needle must be precisely planted and strictly perpendicular. But perseverance will be rewarded.

2] The Elliptical is not, so to speak, congenitally 'Universal' like the Polar, which comes next. For the hour-points must be drawn according to a formula which includes the local latitude. If you move as I did for three weeks in the winter this year (1965) from latitude $51^{\circ} 30' N$ to $36^{\circ} 31' N$ it is a nuisance to have to draw another elliptical to fit the new latitude, though it will give you some intellectual satisfaction if you find that you have done it right. (You can do it, in pencil, by the way, just short of your home ellipse.) How much better to have all the angles marked on your ellipse, going both ways from 0° on your meridian line, a slit or groove running round your ellipse, and little movable hour-buttons to stick in the slit at any required angle. Then if you combine it with the Polar (see page 141) you have a Universal Double.

POLAR DIAL

I have exhumed, also, from the Rees book a Dial as little known as the Elliptical - that is the Polar. My first interest was purely curious: but I now commend it as possibly important, and a worthy subject for experiment.

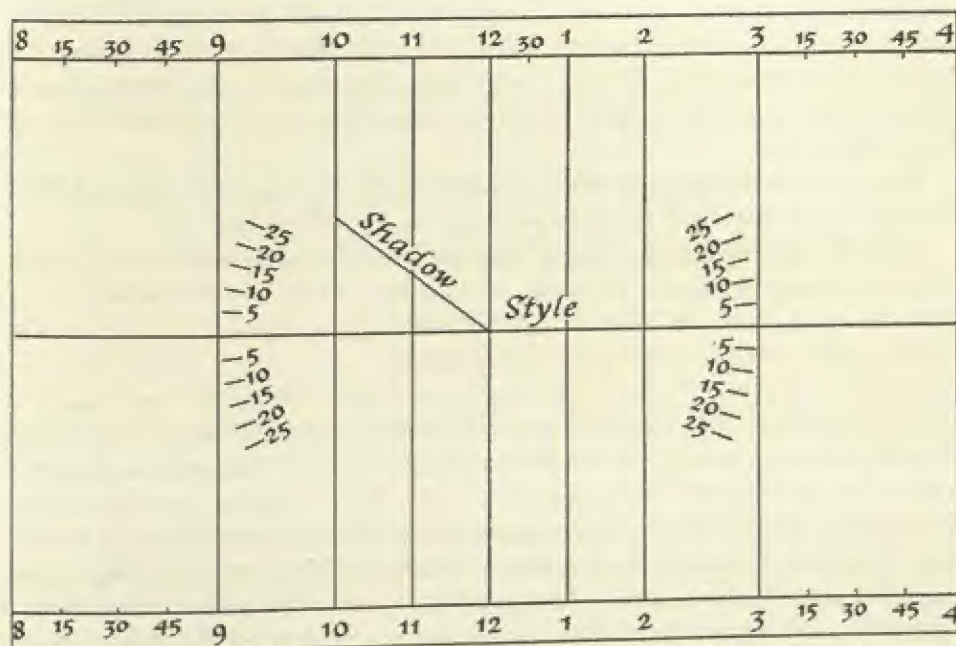
The Rees book (1820) says: 'DIAL, Polar, is that described on a plane passing through the Poles of the world, and the east and west points of the horizon. It is of two kinds, the first looking upwards towards the zenith and called upper; the other down to the nadir called lower.' We won't bother, for the present, about

the lower, which only 'shews the hours of the morning from Sun-rise to six o'clock, and those of the evening from six to Sun-set'.

The Upper Polar, which 'is illumined by the sun from six in the morning to six at night' is not so alarming and difficult as it sounds. It is a sort of half-sister to the equatorial. But here the *dial* is parallel to the Earth's axis and the perpendicular *gnomon* points, I take it, to the Equator. Its face is turned towards the South.

The directions are formidable, but, having fearlessly unravelled them, I found the drawing delightfully painless.

You make a circle, with centre O, and two lines parallel to the horizon at the top and bottom. In the lower semi-circle you draw, from O, 12 divisions of 15° each: and where your lines hit the line you mark the hours as usual - from 8 to 4.



PLAN OF POLAR DIAL Winter - the shadow is *above* the East-West line. The small figures are Declination. In the early hours if the shadow falls on the Declination of the day, the instrument is 'oriented'. Or they can be used to find the latitude. This is only 4 inches from top to bottom - too small.

From these points you draw perpendiculars to the top line and write the same hour-labels there.

Then the 'surface' must be raised to the angle of the latitude, with the *top* end pointing North, to the Pole.

The gnomon, at O, is perpendicular to the Dial, and *must be the length of the radius of your circle*.

Or, says 1820, you can 'on two equal pieces *E* and *C*' (the two 12 points) 'fix a cross iron rod'.

This is beyond me: but you might like to try it.

I find this Polar fellow very attractive. He 'makes a change'. It is not all circles but straight lines. The shadow does not march round and fall upon fixed points as in the other dials. It moves, laterally, very little: it crawls, and shrinks. It slowly recedes during the morning towards the gnomon. In receding the tip of the shadow falls upon the hour, half and quarter-lines (you must draw them too) in turn. It is really a sort of measuring dial; that is why it is so important to have your gnomon exactly of the prescribed length - equal to your radius, OC. Perhaps the Ancient Greeks began it.

When the Declination is South the shadow falls in the top, or Northern, half of the dial. When there is none it creeps along the East-West line.

Now, like the Equatorial, this is a 'Universal' dial. It can be used in any latitude without altering the dial or the style. All you have to do in a new latitude is to alter the angle of its elevation so that the dial is again edge-on to the Poles - in other words is raised to the angle of the latitude.

I had an instrument ready which might have been designed for the Polar. It is a 5-inch protractor (*A*) fastened by a small brass hinge to a block of wood. It can thus be posed at any angle to the horizon from 0° to 90° . Alongside it, centre to centre, is a fixed perpendicular protractor (*B*) which is kept in place by another brass hinge. (Much delicate hole-making and small screw work here.) I use this toy for various navigational experiments which I will leave till later. But I must mention one. In the morning, facing South, I move the prostrate but mobile protractor (*A*) up or down till the style throws a shadow on *the angle of the declination*. Then, believe it or not, *the edge of protractor A points to the latitude on protractor B*. In other words, I can find my latitude in 5 seconds (of course this is a visual reading only, and I should need a micrometer to read my latitude exactly. But why shouldn't I have it? Sextants do).

So I drew a pretty rough Polar Dial, in half an hour: and added, near the West point, the angles of declination up to $23\frac{1}{2}$. I made a hole at *O* and thrust the whole thing on to my existing instrument, where Protractor *A* had been. The style happened to be just the right length: and it works.

This, then, is perhaps the instrument you should take about the country or abroad. If you go travelling, or exploring, to another latitude, your ordinary Horizontal or Vertical will be useless, for they are constructed for a particular latitude. So will the Elliptical – there too the latitude comes into the formula for the hour-line angles. I thought, till I discovered the Polar, that the Equatorial was the only one for you. But the Polar, being 'equatorial' in character too (though the other way round) is also adaptable for different latitudes. Moreover, unlike the Equatorial, it is conveniently usable both in summer and winter, and does not require a 'lower' face in winter.

So you take your Polar with you to Africa – or Kent – whether for fun or safety. You 'orient' the thing facing South, you do the 'Latitude Trick', having got the Latitude you get Local Sun Time: and if you know the Equation of Time and Greenwich Mean Time you can get the longitude – but no more of that now.

If this thing were made professionally the whole thing could be packed flat in a small box. The Dial would sink to the surface – the Style would be removable – or hinged, and Protractor *B* would come down flat – or flattish – over both.

Modernizing the Polar

One Dial which at first seems to respond to the Housewife Theory is the Polar. In Spain I had one or two successful experiments with my Polar cum Elliptical Double (see page 158), simply turning it through 7–8 degrees till it told Greenwich Time. Again, the shadow tends to be slow at the end of the long hour 3–4: but in the middle hours it behaved very well.

But again, when I tried Summer Time on it, I am glad to say that it refused duty. It galloped *ahead* of Summer Time most of the morning – 5 minutes fast at 9.30 – but slowed down, and at 11.30 was dead level. In the afternoon he ran slow almost at once and I abandoned the exercise. Like the other Dials, the Polar says: 'There is a limit.' Just what the limit is deserves experiment.

Apart from the Housewife Trick (pushing the instrument round till it does, for the moment, what you want) I played with many notions for making the ancient Polar tell clock time. I tried a second style, on either side of the main one: this does

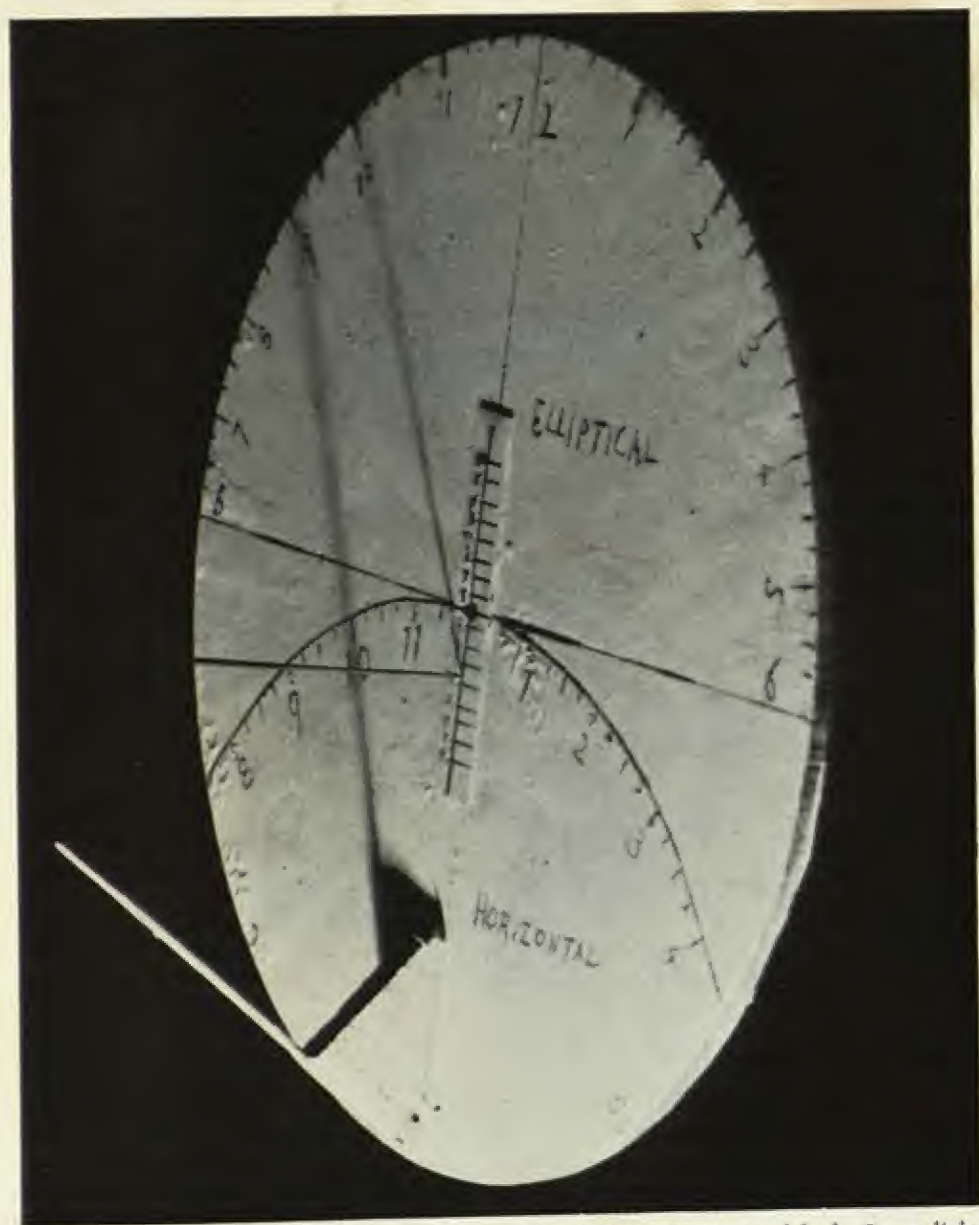
pretty well in the middle hours which are of about the same dimensions: but after 3 and before 9 the divisions do not suit the pace of the second shadow - when it is really 3 by the Sun the shadow goes faster, and fits the wider markings, but if it is really 2 it does not. I tried also putting a second style on the meridian line, but the end of its shadow fell on the same line as the shadow of the main style.

I remembered at last that the governing feature of the Polar is the *length* of the shadow, and so the length of the style. For correct results the style must be exactly the length of the radius, or half the height of the Dial. Given this it shows Sun Time precisely all day. Presumably, then, a style of different length would show a different time, and, by adjustment, a desired time. If the Sun is half an hour behind the Clock a shorter style in the morning - and a longer in the afternoon - should show mean time. What is wanted then is a telescopic style (like, but on a small scale, those television drawing-room aerals). Not being able to construct such things I fitted a longer style with three runners or 'Bobbles'. The middle one is fixed at the orthodox height, to show Sun time by its shadow: the other two are movable to show mean time - morning and afternoon. I came to this conclusion during five days' continuous rain in the South of Spain. When the Sun shone all was well. To see this ancient and forgotten dial showing two different times with one style was an exciting example of 'modernization'.

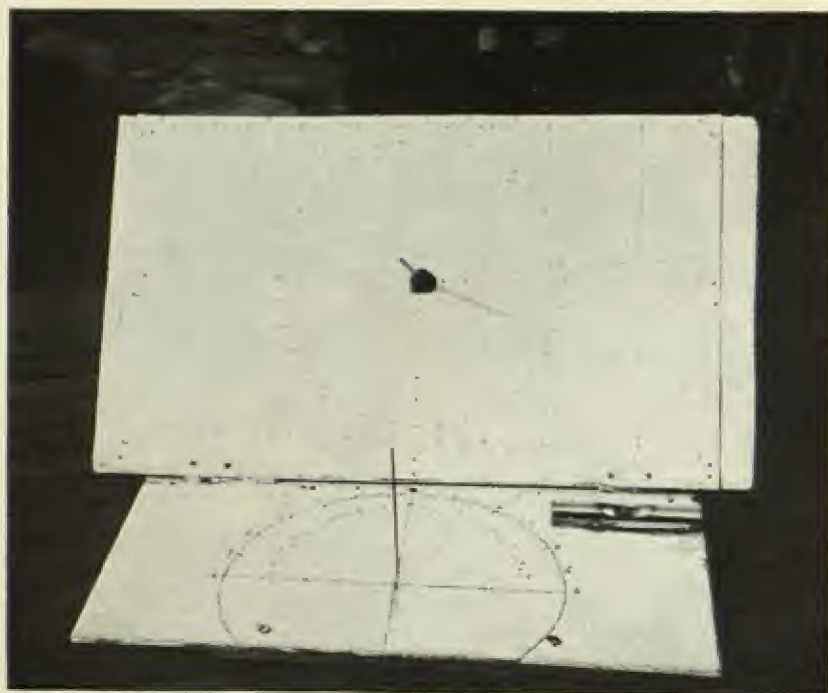
Size

A point to remember when you are constructing a Polar - the smaller it is, in a sense, the bigger: that is, the smaller the radius, and the height of the dial, the more hours you can show. The first one I made was 12 inches long and 7 inches deep, with a style 3.5 inches high - a noble affair. But this showed the hours from 8 to 4 only. I made another 10.6 inches long but only 2.85 inches high. This shows the hours from 7 a.m. to 5 p.m. The outside hours, 7-8, 4-5, are 2.85 inches wide, the hours from 11 to 12 only 0.35 inch. I reckon roughly that a Polar 12 inches long showing 7 to 5 would be 3.2 inches high.

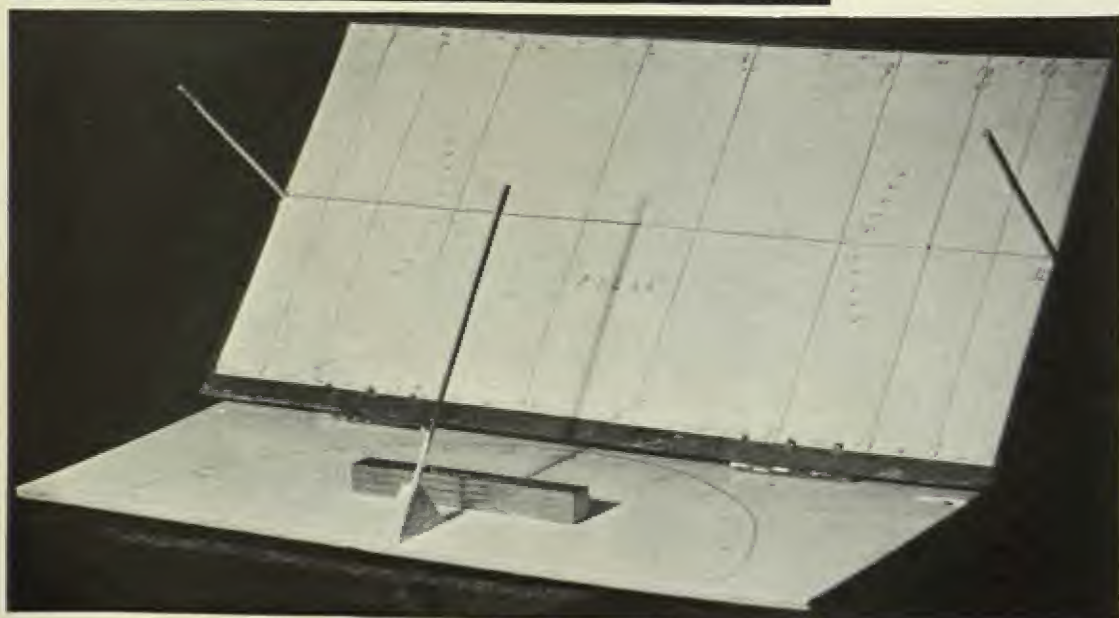
The best trick is to draw the 75° angles first (for 7 and 5), for this will determine the height and length of your dial. The perpendicular to be drawn from the 75° line can be, if you like, the edge of your dial, or you can select a point just short of the edge. Having drawn your 7 perpendicular draw a long line at right angles to the base of it, measure the distance from 0 and draw a parallel the same distance



6. Self-Southing 'Double' - Horizontal cum Elliptical. Both say 10 o'clock. *Lamp-light.*
See page 132.



7a. POLAR (top) and
ELLIPTICAL DIALS
both saying 2 p.m.



7b. POLAR CUM HORIZONTAL. It is difficult with a Polar of respectable size to mark more hours than 8 a.m. to 4 p.m. This new model has a style at each end and is designed to show the hours from 6 to 6.



8a. BOWL OF AHAZ.
Top picture, Bowl of Ahaz, half full of water. There are two shadows – right the shadow of a string being the style of a horizontal dial, left, the shadow of a perpendicular cocktail-stick being the style of an 'elliptical'. Note the angle of the 'horizontal' shadow.



8b. In the bottom picture the water has been siphoned out almost instantaneously. The shadows are faint but in the same position on the rim. But on the side of the bowl the right-hand shadow has straightened out.

8c. BOWL OF AHAB.
In the top picture there
is water in the bowl. In
the second it has swiftly
been siphoned out. On
the rim the shadows
remain on the same
spot; but notice the
different angle of the
right-hand shadow –
to the right of the
thread – on the side of
the bowl. *Sunlight.*



from o on the upper side. This will be your top. Now you can draw your other angles and perpendiculars.

Keep in mind when making your plans the great advantages of a Polar cum Elliptical Double (see page 158).

I have recently constructed a two-way polar – with a style at each end, one covering the morning hours and the other the afternoon. It is pretty complicated to mark, and there has been not enough Sun to give a verdict on it. But the shadow (a knitting needle's) travels a long way without getting 'woolly'.

THE WATER BOWL

(The Dial of Ahaz, and Isaiah – Refraction Theory Examined)

There is one more Dial which, I think, is suitable for the simple amateur like you and me. (I am not going to worry you with the Cylindrical, for example, which is fiendishly difficult to construct and cannot, I imagine, be easily read.) You may care to try the Bowl. It has charm and high historical interest. Designed and done well it would look nice in a South bay window – or, enlarged, in the Italian Garden. If you try the Bowl you will be in good company: for such, some say, was the Dial of Ahaz, the earliest Dial historically recorded.

The Sage of 1820 describes it thus:

DIALS, refracted, are such as shew the hour by means of some refracting fluid.

If a pin or stick be set up, or any point be assigned in a concave bowl or dish for the centre of the dial, let an horizontal dial be applied over the same assigning the meridian line on the edges of the bowl, and marking out the rest of the hour-lines also on the edges of the bowl: take away the horizontal dial, and elevate a string or thread from the end of the said pin over the meridian line, as much as is the latitude or elevation of the pole of the place: then, by bringing the thread to cast a shadow on any hour-point formerly marked out on the edges of the bowl, by a candle or the like, that shade in the bowl is the true hour-line; and if the bowl be full of water etc., when this is done, it will never shew the true hour by the shadow of the top of the pin but when it is filled again with the same liquor.

I confess I do not utterly follow the Sage. At first 'the thread', led to some elevated

point at the rim of the bowl, is to throw a shadow on to a 'horizontal' but watery dial. But then he speaks of 'the shadow of the top of the pin'.

Also, I am not clear about the point and purpose of the thing. I have sometimes thought of erecting a style on the South side of my little pool so that it would throw a shadow on the opposite bank; and you could have an elegant dial in an empty bowl. But why complicate things by bringing in 'liquor' and 'refraction'? Mere prettiness? Or did they have small fish swimming in the sundial?

Whatever the purpose, the performance of the instrument, according to the Sage, depends upon the level of the water: and thereby hangs a tremendous but, I fear, erroneous tale.

You may remember, in the book of the Prophet Isaiah, and in the Second Book of Kings, some references to 'the dial of Ahaz'. Ahaz was the king of Judah in the eighth century B.C. He began to reign within 12 years of the building of Rome, 741 B.C. Hard pressed in war by the kings of Syria and Israel, he allied himself with Tiglath Pileser II, king of Assyria. This warrior assisted Ahaz but thrust upon him, it is said, the beliefs of the Babylonian church, and also led him into the dangerous lore of sundials and astronomy, in which the Babylonians were perhaps the first masters. Hence perhaps the sundial of Ahaz. Ahaz was succeeded on the throne by his son Hezekiah. This king (in chapter 20 of the Second Book of Kings) became sick unto death. The prophet Isaiah attended him, and said: 'Thus saith the Lord, Set thine house in order, for thou shalt die.' Hearing this cold comfort, Hezekiah 'turned his face to the wall', prayed to the Lord, and wept sore.

But the Lord, if he has been correctly reported by Isaiah, changed his mind:

4. And it came to pass, afore Isaiah was gone out into the middle court, that the word of the Lord came to him, saying:

5. Turn again and tell Hezekiah the captain of my people. 'Thus saith the Lord . . . I have heard thy prayer, I have seen thy tears; behold, I will heal thee; on the third day thou shalt go up into the house of the Lord.'

7. And Isaiah said: 'Take a lump of figs.' And they took and laid it on the boil, and he recovered.

But Hezekiah was unconvinced.

8. 'What shall be the sign that the Lord will heal me, and that I shall go up into the house of the Lord the third day?'

9. And Isaiah answered, 'This sign shalt thou have of the Lord, that the Lord will do the thing that he hath spoken: shall the shadow go forward ten degrees, or go back ten degrees?

10. And Hezekiah answered, 'It is a light thing for the shadow to go down ten degrees; nay, but let the shadow return backward ten degrees.'

11. And Isaiah the Prophet cried unto the Lord: and he brought the shadow ten degrees backward, by which it had gone down in the dial of Ahaz.

(The same story is told in Isaiah 38)

Mrs Gatty, in the introduction to her book, writes:

The word 'degrees' in our translation of the Bible has been in the margin and the Revised Version rendered 'steps'; and this reading has given rise to various suppositions. Some writers have thought that a pillar outside the king's palace threw a shadow on the terraced walk, which indicated the time of day. Others have thought that the shadow was cast on steps in the open air 'or more probably within a closed chamber, in which a ray of light was admitted from above, which passed from winter to summer up and down an apparatus in the form of steps'. Others explain the dial of Ahaz as 'a concave hemisphere in the middle of which was a globe, the shadow of which fell upon diverse lines engraved on the concavity'.

This is very learned stuff: but I cannot see why there is this jibbing against the word 'degrees'. This was, almost certainly, an instrument of Babylonian inspiration; and the Babylonians, I read, were the first to divide the circle into 360 degrees.¹

Alice Morse Earle in her *Sun Dials and Roses of Yesterday*² has a much more persuasive and dramatic theory to explain 'the greatest miracle of Isaiah'. This, she says, has baffled not only Bible expositors but men of science. The Dial of Ahaz, she suggests, was a bowl of water, and the Lord – or Isaiah – put it back 10 degrees by altering the level of the water. The Sage, you remember, said that for accuracy the water must be kept at a constant level.

Miss Earle develops this theory with an interesting account of an instrument

¹ *Navigation*, by H. Brinton and P. Moore, published by Methuen.

² The Macmillan Company, 1902.

called the *Horologium Ahaz*, the Sundial of Ahaz, which exists, she says, in Philadelphia, 'a unique relic of those mystics the Rosicrucians'. 'In it is performed the miracle of Isaiah - the shadow is cast backward ten degrees by the refraction of water.'

The instrument, of which she gives a charming picture, was made in 1578 by one *Christophorus Schissler Geometricus ac Astronomicus Artifex*. The bowl, made of 'an alloy chiefly of copper and silver', 'is basin-shaped, ten inches in diameter, with flat movable rim an inch wide . . . it is about 1 and three quarters of an inch in depth and is carried on slender columns. Upon the rim stands the brass figure representing an astrologer, with extended left hand to hold the gnomon, which is, however, now missing . . .' 'By filling the shallow basin with water or any transparent liquid', says Miss Earle, 'it can readily be seen that the indicated time was advanced or retarded as much as the angle of refraction. Thus was the miracle consummated.'

I did not 'see' this assertion very 'readily', for the greatest allowance for refraction made by the sextant-user is half a degree. How, then, could the angle of refraction amount to 10 degrees, as we, and the Babylonians, understood the word? But I liked the drama of the tale. I could see old Isaiah, who, of course, knew everything, stealing down at dead of night and abstracting somehow the necessary water from the Bowl. Longing for it to be true, I tested the tale, at once, on two cold days in January 1965.

I borrowed an earthenware bowl from the garden stock and painted it white. It is 9 inches in diameter ('over-all') and 2.1 inches deep, about the same dimensions as the Philadelphia instrument.

I could not provide a sculptured figure at the rim, and to attach a steady 'vertical feature' to the curved side of a bowl seemed to be difficult. So I devised a simple method, which I commend to others with limited resources. I made a narrow bridge (out of an old cigar-box) and fixed it across the bowl - the upper surface being 1.4 inches from the bottom, and 0.7 inches from the rim. I marked a meridian line on the side of the bowl at each end of the bridge and on the bridge. I made a hole in the centre for a 'horizontal' style. Then I decided to 'modernize' the Dial of Ahaz, and I marked off 24 degrees southward along the bridge and made some holes to take an 'elliptical' style. So my Dial of Ahaz is to be 'self-southing': and I hope, by side-stepping the elliptical style, to make it tell mean time.

Now, as the Sage commands, I drew a circle with a radius of 4.2 inches, and

marked off hour-points (according to my formulae) for (a) a horizontal dial (in black) and (b) an elliptical dial (in red). I cut it out, stuck it on to a circle of cardboard and 'applied' it to the bowl. It fitted beautifully just under the rim. I transferred the hour-points to the rim - 'horizontal' again in black and 'elliptical' in red.

I removed the dial, and thrust half a knitting-needle through the central hole in the bridge, for the horizontal style (a precarious and temporary fitting), and I stuck a cocktail stick in declination hole 20° . The Dial of Ahaz was ready.

That evening I made some experiments by electric light. For certain purposes these can be very useful - the proper alignment of two styles and so on. Here, where the movement of a shadow was in question, they were just the thing. For the electric light, unlike the Sun, is not in constant motion.

I was not surprised to get completely negative results. Whether the bowl was full to the brim, full to the bridge, or a lower point, or empty, the shadow on the rim (the point that matters) remained unmoved.

But perhaps the Sun would have something different to say. Next day he shone generously, and I made some full and particular observations, filling up Ahaz and siphoning him out again with scientific fury. (That evening, by the way, I left Ahaz out too long, and when I took him in the sundial was frozen.)

These are my findings from that cold wet day in the Sun. I have, remember, two styles, two shadows:

1] one, thrown by a perpendicular cocktail stick on 'elliptical' hour-lines. This, whether the bowl is full, half-full or empty, marches straight up the side of the bowl and never shows the slightest objection to passing through water, or ice, for that matter. In all conditions it tells the time with equal accuracy.

2] the other shadow is thrown by a style precariously rigged at the angle of the latitude, and should fall on the 'horizontal' hour-lines. This is not yet so accurate as the other, but that, I think, is because the style tends to sag and sidle. But it is not, as a time-keeper, in the least affected by refraction. When the bowl is brim full it marches straight up the side to, say, 3 o'clock. When the bowl is empty it does the same. Only when the bowl is half-full, less or more, is there any sign of refraction, and then not on the rim, the place that matters. There is then a kink where it leaves the water, and turns to the left or North: but the tip of the shadow, the part that matters, will still hit 3. It is the belly of the shadow, the part under the water, that bends. This is proved by noting the position of the shadow-tip on the

rim, as you swiftly fill the empty bowl, or siphon out the full one. First mark with a pencil the shadow on the side of the bowl. As you fill, you will see the shadow belly away from you, and your mark, like a sail filling with wind. *But the tip of the shadow will still be where it was on the rim.* Now siphon out, and you will see the shadow sag back to its mark on the wall. *But on the rim the tip of the shadow will still be where it should be.* Thus it is clear that the ray, the shadow, though bent indeed by its passage through the new medium, the water, returns, as soon as it leaves that medium, to its original target. It is like a swing-bowler, whose ball may swerve, but hits the wicket in the end.

This theory, however ill-expressed, applies, I claim, to all sundial shadow, whatever the new 'mediums' through which the Sun's ray has passed: and my Ahaz antics, though they have not explained how Isaiah did his miracle, have, I think, powerfully supported my claim.

Friendly navigation experts always seem to assume that 'refraction' must affect the sundial shadow as it affects their sextant 'altitude'. With great respect I should like to examine that assumption.

The Admiralty Manual of Navigation (Vol. II) says:

Refraction is the bending of light from its path when the ray passes from one medium to another. The optical law is that the ray is bent towards the normal - the normal being the line perpendicular to the surface of the medium at the point where the ray enters. . . . An observer always sees an object in the direction in which the ray from that object meets his eye. . . .

So when 'an observer' looks at the Sun, when it is low, and has to fight through different layers of density, he sees it in a slightly false direction, and gets an 'observed altitude' which is higher than the true. So he makes a small deduction from his 'observed altitude'.

The higher the altitude the smaller the deduction. When the Sun is immediately overhead, there is no refraction because the rays are already taking the 'normal' course.

I am not persuaded that any of this applies to my shadows. I have watched a million shadows under all sorts of skies, at very early and late hours of the day - shadows coming and going, strengthening and weakening as light clouds or haze interrupted, or concealed the Sun. I am not, like the sextant man, looking at that 'object' the Sun. I am not, at the moment, interested in his altitude, but in a shadow.

That shadow is caused by a ray of light, and anyone who looks at that ray as it battles, bent, through the layers of density, may well be deceived. But my shadow is the end-product, a stable fact. Otherwise, as the fitful Sun came and went, clear one second, hazy the next, my shadow would surely waggle backwards and forwards. It doesn't. It is either there or not there. It is either strong or weak. But when in a fraction of a second it changes from weak to strong or from strong to weak, *it does not change its direction*. A feeble Sun may make the shadow *shorter*, certainly: and this will affect the Polar dial, or any experiment with the measurement of shadows, but the angle of the shadow will remain the same.

One ray – two shadows?

The absurdity of the Ahaz theory is sadly clear if you remember that a style of sufficient length is capable of throwing a shadow across to the rim without the assistance of the water. If therefore 'refraction' was able to divert a shadow which passed through the water from its proper target you would have the strange phenomenon of a single ray producing two different shadows. Set your bowl in a room with electric light so that the shadow, having passed through the water (or the ice – I have done both) falls upon a particular hour-line on the rim – say 3 or 4. Then pass a card over the water (or the ice) between the style and the hour-line. The shadow will still be there. Take the card away, and the shadow will still be there. But now it has arrived by two different routes. The famous elf Refraction may play his tricks down there under the water, but he has no effect on the rim of the bowl. Not only Alice Morse Earle but, I fear, for once, the Sage of 1820 was wrong.

If all this is conceded, my dials and Sun Clocks are as free from the mischiefs of Refraction as they are from other worries of the sextant man – Height of Eye, Dip of the Horizon, Semi-Diameter of the Sun, Azimuth and so on.

Parallax? Not sure. But this is never more than 9 'seconds' of arc.

Answers to Objectors

Learned friends who have kindly read all this have suggested that I have been unjust to the 'miracle'. I may well be wrong: but I at least have experimented and they have not. Let them try.

Thus challenged, I must observe that the authorities are not only obscure but contradictory:

1] The Sage says that the time is altered by *emptying* the bowl.

2] The Philadelphian instrument says that the trick is done by *filling* the bowl.

In Alice Morse Earle's book (page 395) there is a reproduction of one of the circular panels on the base of the instrument. On it there is a circular inscription in Latin which I deciphered with difficulty and Mrs Earle translates as follows: 'This semicircular shell explains the miracle of Isaiah. For if you fill it to the brim (*labrum* - lip) with water, the shadow is borne back (*fertur retrorsum*) by 10 or 20 degrees (*gradibus*). Moreover it indicates any common hour of the day, with what is called the hours of the planets.'

The author does not mention that at the business end of the Bowl, that is, under the 'thread or string' there are the words:

HOROLOGIUM HORIZONTALE

AD ELEVATIONES POLI

GRADUS

47 48 49 50 51 52

This fits. Schissler made sundials at Augsburg, in Bavaria - Latitude $48^{\circ} 22'$ North: and 'made much ingenious apparatus . . . for Emperor Rudolphus II' who was crowned at Regensburg - Latitude 49° . I thought of writing to the Philadelphia Museum, and asking if they have ever done 'the miracle' with their beautiful and precisely made instrument. But the Latitude of Philadelphia is 40° - so I suppose they can't. I wish they would take it on a journey and try. But they will have to go to Canada or Newfoundland. Till this has been done let no one tell me that I am being unjust.

I may well have misunderstood the obscure and conflicting instructions. One of the Friends of Isaiah said he thought that the horizontal dial might have been marked on the *bottom* of the bowl, in which case, I agree, the shadow can be shifted (though not by 10°) by filling the bowl. But who would mark a dial on the bottom of a bowl, thus curtailing its usefulness, through shutting off the Sun, at both ends of the day?

I tried this, however, with (a) a vertical pin in the centre of the bowl, and (b) a sloping (horizontal) style. I marked both shadows on the bottom, the wall, and the rim of the bowl. Then I filled it to the brim.

The vertical pin shadow did not move at all throughout the evolution.

The 'sloping' shadow moved about three degrees on the *bottom*, but remained motionless on the *rim*. When I emptied the bowl the bottom shadow returned to its mark: the rim shadow, and the vertical, remained *in situ quo*.

All this was by electric light. The shadow on the bottom moved *back* on the afternoon side, forward on the morning side.

I must add that the picture in the Earle book shows the hour-points, marked in Roman figures, just below the *labrum*, lip, rim, or, as the Sage says, 'edge' of the bowl. Moreover, the Sage says, remember, that the bowl is 'to be full of water etc.' when his instructions are carried out. How anyone is to draw a horizontal dial on the bottom of a bowl full of water I do not know.

Nothing fits the tale, it seems to me. But if anyone, by experiment, can prove me wrong, I shall be delighted.

What, then, did Isaiah do?

I have toyed with the notion that in the hours of darkness he might have tampered with the *style*. If it was a pole-type style as loosely poised as some of mine, this would be easy. He would have to raise it in the morning – or lower it in the afternoon. The following shy calculations will be more intelligible if you refer to the table of 'horizontal' angles on page 79.

His latitude was 32° . The angles which govern the hour-lines for a horizontal dial are measured outwards – East and West – from the meridian line. The higher the latitude the larger the angles. Therefore, to push the shadow *backward* Isaiah must make his angles larger, and pretend he is in a higher latitude. That is, he must raise the style till it is at the angle of a higher latitude where the hour-line angle at any given time is 10 degrees larger (or 40 minutes slower) than it would be in Latitude 32° .

The best time for his miracle would be between 8 and 9 a.m. The angle for 8 in Latitude 32° is $42^{\circ} 32'$ and in Latitude 50° it is $52^{\circ} 59'$: at 9 the angles are $27^{\circ} 5'$ and $37^{\circ} 27'$. So he would have to raise his style by 18 degrees to keep the shadow back by 10 degrees for an hour. It sounds a lot, but it does not look a lot, and the untutored would probably not notice any difference.

The shadow would not be so backward all day. At 7 o'clock it would be only $7\frac{1}{2}$ degrees behind. But Isaiah could use this for his own advantage and the glory of the Lord. 'Lo' he could say at 7: 'Lo! the shadow goes backwards. At the 8th hour it shall be 10 degrees backwards, as the Lord said, and again at the

9th hour. Thereafter it shall go on again.' And accordingly at 10 it would be $6^{\circ} 51'$ behind, at 11 only $3\frac{1}{2}$ degrees. At noon it would be back to normal - for the orientation of the instrument had not been disturbed. There would be general wonder. Again, during the siesta Isaiah would restore the style to its rightful angle. If he left it in its new position the shadow would go ahead of time in the afternoon.

This is the Herbert Theory of the Miracle of Isaiah. If anyone knows of a better I hope he will let me know. Certainly it was not done by 'playing with water'.

No Briton, I fear, can emulate Isaiah in these latitudes - that is, in the morning. I reckoned that to put my shadow back 40 minutes at 9 a.m. I should have to push the style back more than 40° , so that it would be leaning over backwards. And lo, in the morning it was so.

But in the afternoon you could set your shadow backwards exactly 10 degrees between 3 and 4 p.m. by *depressing* your style through 18 degrees. (See what strange results can follow if you start tampering with a delicate sundial.) I have done this miracle myself - without the aid of water. I made a tiny horizontal with two styles of silken thread - one tells Sun Time; the other (in the afternoon) Isaiah Time, 40 minutes slow. I call it British Winter Time.

One way and another, I have formed a surprised affection for this ancient dial, and am proud to have made it both 'self-southing' and 'two-timing'. As a small affair it should look very well in a window, and I hope that some British artist in ceramics, or metal-work, may be inspired to emulate Mr Schissler and produce a Bowl of Ahaz supported by slender pillars, or by comely nymphs or naiads. The artists will, I hope, provide a figure on the rim, or other high point, to uphold the 'horizontal' style. In the middle must be a small 'style island'. The base of the horizontal style will be fixed here, and there must be room for the 'elliptical' style, to mark 24° each way, North and South, also room for it to step sideways and tell clock time.

On a larger scale I see delightful Pools of Ahaz, again with a style island ('horizontal' only), hour-markers on the bank (movable for clock time) and perhaps fish and water-lilies in the water.

If you want to know how long your style must be, draw a little diagram. Draw first, to scale, a line representing the distance between the centre of the island and the bank. Then draw your style, at the angle of the latitude. Then

from the bank end of the line draw a line at the angle of elevation of the highest Sun of the year, when your shadow should just touch 12 at noon. This comes on June 21 – and in the following latitudes will be:

Latitude	50	Altitude	$63\frac{1}{2}$
	51		$62\frac{1}{2}$
	52		$61\frac{1}{2}$
	53		$60\frac{1}{2}$
	54		$59\frac{1}{2}$
	55		$58\frac{1}{2}$
	60		$53\frac{1}{2}$

The point where this line meets the other is as far as your style needs to go.

DOUBLE – AND TRIPLE – DIALS

These are fun to make: but the duplication, I feel, should have some practical purpose. In the 1820 book there is a picture of a 'Dial on Three Planes' – a Vertical cum Equatorial cum Horizontal Dial. One solid style serves all three, the Equatorial being rather inelegantly straddled over it, half-way up, between the Vertical and the Horizontal. This is a fine piece of work, and it illustrates very well the truth we established earlier (page 52) that the differences in the hour-divisions are simply caused by the different angles at which the Sun strikes the 'plane' of different dials. But the combination seems to have no practical purpose. All three dials, if accurately constructed, will tell the same time in a different way. But it will be Sun Time only, and if the instrument is not correctly oriented they will all be wrong together. It is therefore what I call a 'show off'. Two practical purposes can be served by a combination of dials:

- 1] accurate orientation without a compass – or, as I say, 'self-southing'.
- 2] the telling of Mean Time as well as Sun Time.

Some of the Herbert combinations do both.

(1) *Vertical cum Horizontal cum Elliptical*

I am rather proud of this instrument, which is modestly made of wood. A single silken thread serves both Vertical and Horizontal for 'style': and (at the moment, November) a needle serves the Elliptical.

At the base of the Vertical wall is one of my 6-inch 'rounds'. On the Northern semi-circle (nearer to the wall) is drawn a horizontal dial (6 a.m. to 6 p.m.) and on the Southern side an Elliptical (the upper half of the ellipse only).

The horizontal circle is fastened to its base by a single screw in the centre. Made fast to this screw the thread leaves the horizontal dial at the angle of $51^{\circ} 30'$ (the latitude) and passes through a hole in the vertical wall at the angle of $38^{\circ} 30'$ (the co-latitude).

(On the other side of the wall - a practical hint - I make the thread fast to some small object of sufficient weight to keep the thread taut. This is more convenient than making it fast to a screw, especially if it has to be renewed.)

The vertical semi-circle is fastened to the wall and in theory should be movable, pivoting at the base of the style. But I am keen on my thread and found it difficult to have both. So my vertical is screwed on to the wall, leaving the style hole free for the thread.

The horizontal round is movable, pivoting on the central screw.

I start with three 'meridians' in line.

1] *Self-Southing*. If both the Vertical and the Horizontal tell the same time this is very gratifying. But they have the same style, and it merely means that they are accurately marked. Both may not be properly 'oriented' and be telling the *wrong* time. But the Elliptical is a dial 'of a different nature'. It has a different style. So if all three say the same it must be right and the whole is oriented.

2] *Mean Time*. Having established that I turn the horizontal circle till both the Horizontal and the Elliptical are telling Mean Time (as explained before).

So the whole instrument, self-southed, is telling both Sun and Mean Time. This is worth doing. It would be better still if the Vertical (more easily seen) were telling Mean Time. Here is a problem for better workmen.

(2) *Horizontal, Equatorial and Elliptical*

Here I have a horizontal under the canopy, so to speak, of an adjustable equatorial dial. The style, a knitting-needle, is firmly bedded in the centre of the underside of the equatorial, whose style must be at the angle of the latitude too. On the horizontal round I have drawn an elliptical. The horizontal pivots on the base of the style. I proceed as in (1) above, but in this case, if desired, all three can tell Mean Time.

There are many possible combinations.

(3) *Horizontal (Adjustable) and Elliptical (Self-Southing)*

This is what the ancients called (I think) the Analemmatic. It can be done in two ways: (1) Horizontal and Elliptical separate but parts of the same instrument. (2) Horizontal and Elliptical using the same surface, e.g. a 6-inch round. I have done both.

(4) *Vertical (Adjustable) cum Elliptical (Self-Southing)*

But all these are limited to one local latitude – or near it. If you move to another part of England or Scotland you must alter the angles of your horizontal and set your style at another angle. This is why I conclude with a magnificent Universal Double.

(5) *Universal Equatorial (Adjustable) cum Polar (Self-Southing)*

Both these Dials, as I have explained, are related to the Equator – in opposite ways. Each has a style perpendicular to the dial-face. Both, then, can operate in any Latitude – provided only that the dial-face is tilted so that in one case (the Equatorial) it is level with the Equator and in the other (the Polar) it is at right angles to it.

So you can take them anywhere (with the usual limitation about the upper and lower faces of the Equatorial).

The duplication can be done in two ways:

i] Put a Polar, facing South, under the overhang of an Equatorial facing North. The Polar, in spite of their equatorial affinity, is sufficiently different from the Equatorial to claim 'self-southing' properties. The two shadows move in the same direction; but the Polar shadow, as I have explained, moves in a wholly different way. Therefore, if they both tell the same time it must be right and the total instrument is 'oriented'.

ii] Put an Equatorial and a Polar side by side on the same circle, with a perpendicular protractor between them.

Then by my 'Latitude Trick' (see page 142) you will be able to 'get your latitude' in 5 seconds, and set your dial(s) accordingly.

Either way you get over the disadvantage of the Equatorial, that in the winter-time, when the Sun is below the Equator, it casts no shadow on the upper face of

the dial. If you fit a lower face it does, after a few days, show a shadow, and if you put it somewhere above you it works just as well. But you have to peer, and it is not quite the same thing. The Polar, though, so far as I know, works all the year round - either above or below the East-West line. So when the Equatorial became awkward you would turn to the Polar: and it is the Polar that 'does the Latitude Trick'.

What would happen the other side of the Equator? I suppose you would simply turn the whole thing round - 180° - but alter the marking.

More of this when we come to 'Cascanio' - Part II, page 175.

(6) *Polar cum Elliptical - Universal (Self-Southing)*

I made this in scientific, or, shall we say, mere curiosity, but I found in Spain that I had invented a practical and useful instrument. I thought it would be amusing to put together the two unusual, forgotten dials I dug out of the old Greenwich book. They are a strange couple, never wedded before, I swear. Both have a perpendicular style, but they work in utterly different ways. One (in the Polar) points to the Equator, the other (in the Elliptical) points to the Zenith. The Elliptical shadow falls on hour-points, the Polar shadow touches hour-lines, on a slightly different place each day. They are so 'different in nature' that when both, accurately marked and set, tell the same time you may fairly say that that *is* the time, and therefore your meridian lines lie truly North and South. This oddity has a magical efficiency in many ways.

1] It is self-southing in more than one way. The Elliptical goes into action earlier than the Polar: but in the early hours, before the Polar shadow is telling time (because the shadow is still too long) the shadow will fall upon the angle of the Declination. You can approximately orient the instrument in this way; and what the Elliptical says will then be approximately Sun Time - to be checked later when the Polar begins to tell the time.

2] The Polar, by nature, is universal. You have only to raise the dial to the angle of the latitude. If you are going to remain in the same latitude a hinged support of the right height will do (you can find the right height by drawing a little plan). If you are going to move from latitude to latitude you should have a graduated quadrant such as was recommended for the Equatorial Sun Clock (page 103). The Elliptical is not naturally universal but can be made so by the method described on page 140.

If, once again, you were sure about the South but not about your latitude you could find your latitude in the early (or late) hours by raising the Polar dial till the shadow fell on the angle of the declination.

3] Both the Polar and the Elliptical, as we have seen, can be made to tell Clock Time: so, if you will, you can have a self-southing Greenwich Timer. At Marbella, in Spain, where there are no clocks, it was very difficult to get the exact time, and my watch began to falter. I frequently corrected my watch by this instrument. One morning it told me that my watch was four minutes slow. I rang up the hotel, and, for once precise, they said that it was so.

You may be one of those fortunate winter Sun-seekers who pass from the Canaries to Marrakesh, from Marrakesh to Gibraltar, from Marbella to Madrid. In all these places the Polar cum Elliptical will give you, first, Sun Time and the South and then Greenwich Mean Time.

It is a practical, as well as a sentimental, thing to cling to Greenwich Mean Time in foreign parts. Some have Summer Time, and some do not. Some keep wholly illogical times. In Tenerife, which is in $16^{\circ} 40' W$, a Spanish possession, they keep Greenwich Time. In Marbella, Spain, which is in $4^{\circ} 54' W$ they use Summer Time all the year, so the clocks in winter-time are one hour ahead of Greenwich, and the difference between Sun Time and Clock Time, in March, was 1 hour 28 minutes. If you cling to Greenwich Time, as to a rock, you are equipped to cope with all the local vagaries. I always carry two watches abroad, G.M.T. on my left wrist, and Local Times on the starboard hand. Both gave some trouble at Marbella, so I was glad to have my trustworthy Double with me. Not that time matters much in Spain.

(7) *Equatorial cum Vertical* (see page 125)

(8) *Bowl of Ahaz - Horizontal cum Elliptical*

PART TWO

Abroad



THE HERBERT HEIGHT-FINDER

I have sometimes called this instrument the Poor Man's Sextant. But it is not really a good name, for it is not at all like a sextant, except in its purpose, which is to find the height, or Altitude, of the Sun – that is, the angle between the Sun, Yourself, and your Horizon.

You probably know that if you point a pencil or pole or knitting-needle directly at the centre of the Sun it will throw no shadow. That is the principle of this very simple device. It consists of (a) an ordinary semi-circular protractor standing at the perpendicular on its straight edge; and (b) a pointer fixed at the bottom of the central line of the protractor (that is, the line which at the top is numbered 90°), but movable, so that it can be pointed directly at the Sun, and the angle at which it is pointing read off on the protractor.

Practical Notes

a] *The Protractor.* I find the best way for an amateur to make a protractor stand at the perpendicular is to attach it to a brass hinge (or two), screwed into the base. Thus, for travelling, the whole contrivance can be folded flat and packed in a shallow box.

b] *The Pointer.* We now require some plane or surface on which the pointer can be seen to throw no shadow:

i] For this I pierce with the pointer a small white disc (cardboard or wood) and fix it above the protractor and not far from the peak of the pointer. Then, at first, I moved the pointer up and down till there was no shadow on the disc, and I said: 'That is pointing to the heart of the Sun. The Altitude is So-and-so.'

ii] But here is a query for the experts and experimenters. It occurred to me that the centre of the Sun is a pretty big place, and that this might mislead my instrument. So I tried a new device, a pointer which should throw a shadow, but only a small one, at the moment of truth. The simplest thing is an ordinary pin fixed at the end of the pointer (I do not say that I have found the 'fixing' simple, but for the professional it will be child's play). When the pointer is pointing true the shaft of the pin duly throws no shadow: but round its base is the tiny circle of

the shadow of the pin-head. When the base of the pin is in the centre of the circle, I judge that we are indeed aimed at the Sun's centre and take my reading of the altitude.

The experts, no doubt, will be able to say which method is the better.

c] The base of the pointer should be attached to a lever, so that it can be easily controlled while the observer is watching the shadow and will remain stationary at the point selected.

d] The lowest division on my protractors is a quarter of a degree or 15 'minutes' of arc. So I can make no claim to accuracy nearer than 15 'minutes', but am disappointed if I don't get that. In the Mediterranean I took many 'sights' at the same time as the Captain of a yacht, using a sextant, and our results were agreeably close. But he was making his readings with a vernier or micrometer, and I must have that too. The vernier would be attached to the pointer, and poised over the degrees on the protractor.

Merits

This instrument does not, of course, claim to do as much as the sextant, which can measure angles of all sorts, vertical and lateral, which have nothing to do with the Sun. But for its single purpose, to find the altitude of the Sun (or even a nice bright Full Moon) it has, I shyly claim, some merits. A kindly Admiralty officer allowed that, in theory, it was '100 per cent correct'. But he did not see any practical future for it. For, he said, 'the Admiralty provide us with sextants'. Yes, Sir - but the Admiralty do not, so far as I know, provide sextants which require no 'horizon' - and no 'corrections' of their readings.

The Horizon

In some of the Mediterranean experiments I have mentioned we were in harbour with a high mole between the yacht and the sea - and the Sun. This did not worry me: I did not need to see the sea. I sat on the quarter-deck and pointed my pointer at the Sun: and if at Noon-by-the-Sun the protractor said 70° , that was that - I did no more. But the Captain had to climb to the top deck, so that, over the mole, he could see the horizon, that wonderfully drawn boundary between sea and sky. To this line with his clever mirrors and magnifying-glass and coloured

shades he 'brought down' the Sun – a splendid toy balloon of a Sun, perhaps yellow, perhaps vivid red or even green. This round marvel, adjusting always, he made at last to touch the horizon line with its smooth bright bottom – or what they call 'the Sun's lower limb'. It danced about, not easy to control, like those white balls that balance on the tops of fountains at a fair. Still adjusting he swung his sextant gently to left and right, so that the bright red ball brushed the blue horizon like a chaste, quick kiss, at one particular point. A wonderful sight – and a most worthy scientific achievement. At last he stopped, and shouted, and I noted the time to the nearest second. Then he read what his instrument had to say – either with a clever 'vernier' and a magnifying-glass or, better still, a 'micrometer', which records the altitude in degrees, minutes and seconds of arc, so that Man has nothing to do but read it.

69° 45' the sextant says, perhaps. That is his Observed Altitude. But now he must make 'corrections' to get the True Altitude. First, he may have an Index Error – a congenital defect of his instrument which requires 1 'minute', or 2, to be added to the Observed Altitude, or subtracted. Then, he must subtract the 'dip'. Because he is standing high above the sea his Observed Altitude is greater than it would have been if he had taken his sight when truly level with the horizon. The difference is called 'the dip of the horizon': but to find this he must know exactly, in feet, what is his Height of Eye (above the Horizon): and then he must do a sum (if it has not been done for him in a book).

Then the navigator has to look up the Semi-Diameter of the Sun. When he talks about the Sun's Altitude he has in mind the centre of the Sun: but, as we have seen, with his old-fashioned sextant he gets only the altitude of its Lower Limb: so he must add the Semi-Diameter (which varies between 14'·7 and 16'·0 – according to the distance of the Sun).

Finally, there is the little matter of Refraction and Parallax. Parallax seldom comes to more than a few 'seconds' which must be added to the Observed Altitude. Refraction must be deducted, for the diversion of the Sun's rays makes the Sun seem higher than it is. It varies with the altitude, is more when the Sun is low and has to penetrate the murk, and almost nothing when the Sun is high. With an altitude of 70° you should allow 0'·4 for Refraction and 0'·06 for Parallax.

Now, it is true that my Captain did not have to do all this adding and subtracting: for the almanacs have a convenient 'Sun Altitude Correction Table', which works out the total 'Correction' to be applied for different altitudes and Heights

of Eye. But he had to find the right book, and the right page, and do some 'mental interpolation' and a small sum, before he could announce, perhaps, that his *True Altitude* was $69^{\circ} 58'$.

Meanwhile, I was sitting quiet, quite happy with my 70° . 'Dip' does not trouble me, because I do not use a 'horizon'. The Semi-Diameter does not trouble me, for, as I have explained, I get the Altitude of the Sun's Centre directly. Refraction I could safely ignore with the Sun 70° up in a clear blue sky. I maintain myself that refraction does not affect the sundial shadow.

But let us go back to the Horizon. By 'horizon' the sextant-man means a *good* horizon, a clear firm line. The Sun may be blazing down on the ship when the horizon, towards the Sun, is vague with mist or obscured by cloud. This happens often after a storm, or in foggy waters like the neighbourhood of Lisbon. In such conditions, at the dramatic hour for 'Sun-shooting', the sextant is useless. But, with great respect to the Navigators, my little instrument, properly made, would work very well - in a big ship certainly, and in others, if the sea was not unreasonable. Even in a rough sea the sextant-man is not always deterred. He waits for the middle of a roll and shouts 'On' at last to his time-keeper. But in the conditions I have mentioned the sea is generally reasonable. You would have one eye on the shadow and another on the spirit-level and choose your moment.

Then there is the land - the explorer, the traveller, the secret agent, the Marines landed in strange country. On land the sextant is no use, unless you have an 'artificial horizon', a bath of mercury or oil. There is that elaborate and weighty instrument the theodolite. But few explorers in desert or jungle are likely to have room in their packs for sextants, mercury baths, or theodolites. My little fellow would weigh perhaps 8 ounces, and anyone with an elementary knowledge of the noon-drill could get his latitude wherever the Sun shone, even in the depths of a forest.

I have forgotten the full story of those poor fellows who were massacred some years ago in the jungles of Brazil. I remember that they had found the wrong river. If their Latitude was awry the Height-Finder would have helped them to find the right river. If it was the longitude they should have had a Sun Clock.

I have patented the Height-Finder. But if the Royal Navy will make a few they shall have it for nothing.

Stationary Shadow [1]

I deal with my 'Stationary Shadows' later. But here, meanwhile, is a surprising, and, perhaps, valuable property of the Height-Finder.

Mark on the disc a North and South line, and an East and West line – the pin being at the point of intersection. Aim the instrument due South. About two hours before noon, or even earlier, raise, or lower, the pointer till the shadow of the pin rests on the East-West line. That shadow will remain on or about that line till noon, and will then lie along the same line on the other side till about two hours after Noon-by-the-Sun.

A mere curiosity? No. Now look at the protractor and see what angle is registered there. *It is what will be (or was) the Altitude at Noon.*

I have not the least idea why this should happen, but it does. No doubt the experts could explain it. I can do the same trick with another instrument in a different way (see page 178). I told an astronomical expert about this, and, without explaining the thing, he wrote: 'If the instrument is set two hours before noon there will be an error of two degrees at noon.' I dutifully made many experiments (in the South of France) to test this assertion, but never detected a difference so great. There was generally a slight movement in the two hours, though some days the shadow did not seem to shift at all.

But if, as I must assume, the expert is correct, there must be some way of allowing for 'the error', as so many other errors are allowed for in the Nautical Almanac – according to the latitude, the declination, the altitude, etc. One more Table should be added to the books.

I have told no other expert about the Height-Finder's performance, and hope that it may be tested now. Error or no, the central fact remains that this shadow does lie on the same line for about four hours and during those hours seems to indicate the Altitude at Noon. This is surely a property which, subject to expert, reservations and skilled adjustments, might be put to practical use.

If it can be made trustworthy, imagine the advantages. Those poor fellows in the Brazilian jungle were probably not full navigators, but they could easily learn the simple drill for finding the Latitude (given the Altitude and Declination) at Noon-by-the-Sun. How convenient if they could do that simple sum at 10 a.m. instead of having to wait for Noon-by-the-Sun.

I fancy too a charming scene on the bridge of some great ship in mid-ocean.

Just before Noon-by-the-Sun the officers assemble with their sextants: but at five minutes before Noon the Sun is obscured by clouds or the horizon by mist. The Sun cannot be shot. But the Navigating Officer says: 'Oh, that's all right. I've got it in the fridge. I took the noon altitude (where we were) at 10 o'clock this morning. We've steamed X miles since then and our Latitude is So-and-so.'

UNIVERSAL SUN CLOCK - MODEL FOUR - NAVIGATIONAL

Model Four, which is intended for place-finding, on land certainly and possibly on sea, and in the air, will be constructed on the same lines as Model Two - that is, the longitude will be marked - west to the left - on the Ring, and the morning hours, on both Dial and Ring, will be on the right. The names? Superfluous, perhaps, but might be useful to the explorer or the lone mariner.

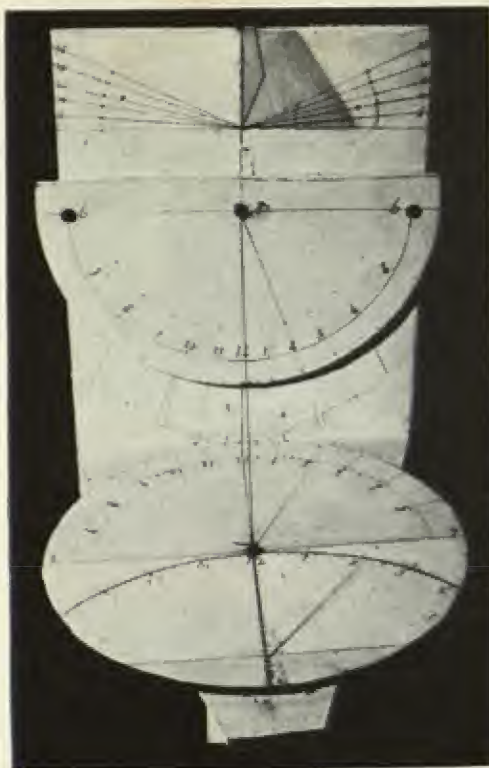
But there will be some additions. The navigators generally have a rough idea of where they are, and, both under the old-fashioned methods or the new, they *assume* that they are in Latitude This and Longitude That. They take a sight of the Sun and compare the result with their assumptions. The claim of the Sun Clock is that the traveller who has little or no idea of where he is can find out exactly.

You are a secret agent, bound on a mission, shall we say, to somewhere in Eastern Europe where you are to be dropped by parachute. You went to sleep in your harness, you wake up on a bright morning in a clearing in woody country. Something, you know, must have gone wrong, for you were wakened suddenly and told to drop at once. Now - where are you? Poland, Lithuania, Germany, France? It is a mild summer's day - July 17 - and you might be anywhere in Europe.

Your watch, which you set last night to Greenwich Time, is still ticking away. It says 5.30, but here the Sun is well up. You take from the little bag on your shoulders your Sun Clock, packed in a flat box, and your Height-Finder, packed in another. You unpack both and make them structurally ready for action. This includes ensuring that they are level, either by small spirit-levels or four levelling-screws.

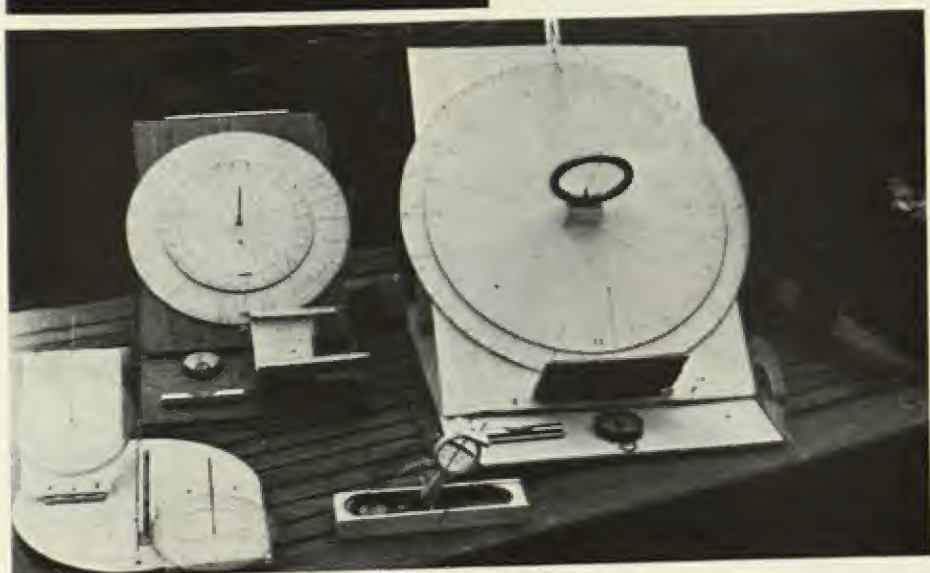
Now you have three tasks:

- a] to find the true South and correctly 'orient' the instrument.
- b] To find the Latitude and correctly set the Clock.
- c] to find the Longitude.



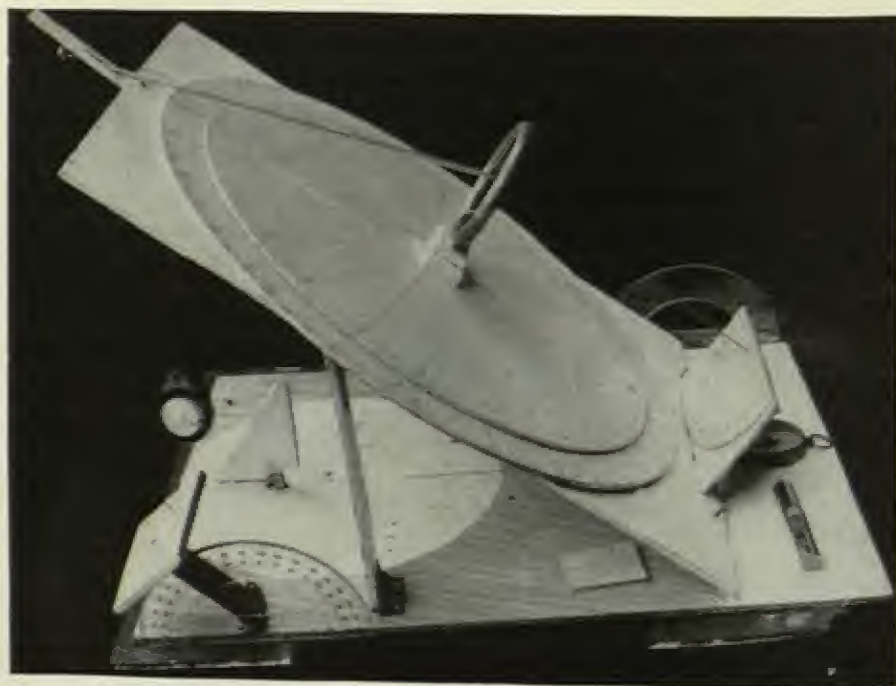
9. TRIPLE DIALS. Elliptical (foreground), Horizontal and Vertical Dials in one. Vertical telling Sun Time - Horizontal and Elliptical Mean Time (the Sun is slow). At the top the Herbert Compass. *Electric light.*

10 below. PROTOTYPES. A group of prototypes. On the right 'Gibraltar', the first model - Ring, diameter 14 inches, Dial 12. The brass curtain-ring carries a style of silken thread. Note the second style primitively mounted at the top. On the left Cascanio. In the foreground the first Height-Finder - 'the smallest sextant in the world'.





II. THE FIRST HEIGHT-FINDER – 'smallest sextant in the world' – Protractor (1s 6d), plastic magnifying glass (1s 6d), child's compass-box (free), wife's hair-clip (free). Pretty accurate. Why 2 nails on top? In case one gets knocked off the perpendicular.



12. GIBRALTAR Equatorial Sun Clock, first model – Dial, diameter 12 inches, Ring 14 (too large). The elegant brass curtain-ring supports a style of silk thread – note the second style, top left, to be set to the declination. Down left, combined Height-Finder and Navigator. Under the Dial a 'Horizontal'.

(The process, as described here, may sound long and complicated, but I can do the whole thing in two or three minutes: and so could any man who had been trained in the use of the instrument.)

First you do something which will contribute largely to all three purposes. From the box you take a card which gives you the Sun's Declination that day for 8 a.m. and 12 noon. You set the 'runner' on the graduated style to the required figure - it is $20^{\circ} 10' \cdot 8$ at 0800 G.M.T.

(1) *To find the true South*

This has been discussed under 'Orientation'. As a preliminary you use your pocket compass (you cannot use Mr Chichester's Sun Compass yet because you do not know the *Local Time*).

But the Sun Clock (Model Four) has other aids.

THE NAVIGATOR

Here I must introduce another new instrument, whose long title is the South-Altitude- and even Latitude-Finder. I will call it, for short, the *Navigator*.

This consists (at present) of two protractors and two brass hinges. Protractor *A* is circular. It is affixed to a 'plane' or bit of wood which faces South and is movable on a hinge - but most easily movable backward, i.e. away from the Sun. Fixed in the centre is a 'style' - a needle perhaps. Protractor *B* stands perpendicular beside it (like the protractor in the Height-Finder) with its *edge* to the South. Thus it is possible at any moment to measure on Protractor *B* the angle at which Protractor *A* is standing in relation to the base - which represents, if properly levelled, the horizon. The Navigator is screwed to the base of the Clock, near to the dial, at the North end. Now move Protractor *A* till its edge is opposite the angle of the Declination (20°).

Then with the Height-Finder take the Altitude of the Sun.

Quickly, then, look at the shadow thrown by the needle on Protractor *A*. If all is correct it should be lying on the angle of the Altitude you have just taken. If it is not quickly move the instrument left or right until it is. *Your Clock will then be on the line of true North and South.*

Later you may get your southing another way. This is quicker, and more convenient if you have no companion, to take the Altitude and tell you the figure. Use

the style of the Navigator (which should, by the way, be as long as possible) on the principle of the Height Finder. Point it at the Sun till there is no shadow at its base. 'A' will then be pointing to the Altitude on *B*. Without bothering to read it, turn the instrument till the shadow falls on the *declination*. The instrument should then be pointing true South. (This works, for a period, after 10.)

This may sound like magic, delusion, or fraud. But it is only one illustration of the Sun Clock's claim that it contains every element of the Spherical Triangle visibly in action. The navigators, in their protracted calculations, bring together Altitude, Declination, Equation of Time, the Pole, the Hour Angle, and finally Latitude and Longitude. The Sun Clock brings them together too, but visually, without calculations. It is like a jig-saw puzzle. Put one piece in the wrong place - too large or too small - and the whole puzzle is wrong. Make one correction and all is right. Here you have the declination and the altitude working together, so that on Protractor *B* you have PX (90° minus Declination) and on Protractor *A* you have ZX (90° minus Altitude). This gives you the position of *P* in relation to *Z* - in other words, the 'orientation'. What you have not got is PZ (90° minus Latitude) - but it must be there.

(2) *To find the Latitude*

This can be done in two ways, both employing the Declination:

i] Raise the Dial till the shadow of the 'runner' on the style falls on the rim of the Ring (or the Dial, if that is what you have arranged - see page 129). Now that the Clock is properly oriented this should mean that the Dial is correctly at the angle of the Co-Latitude. The Co-Latitude is PZ . You have completed the triangle.

ii] Turn to the Navigator and move Protractor *A* till the shadow falls on the angle of the Declination. The edge of Protractor *A* should then be opposite the Latitude on Protractor *B*.

(NOTE: All this, in my own poor instruments, is pretty rough, though they might do in the Sahara. The South and Latitude-finder should have a micrometer which would register exactly the angle taken by Protractor *A*. Then, I suppose, Protractor *B* would be superfluous, and the little instrument would be more 'packable' still. I should like, too, if possible - I do not fully understand these things - a micrometer attached to the dial-gear so that the co-latitude angle could be precisely recorded.)

Now, then, you have your latitude which is, shall we say, 52° North. You think you may be somewhere in Northern France. On the Dial the Sun is busily telling you Local Sun Time – nearly 8 a.m. You see, among the brief particulars they have given you, that the Equation of Time at midnight was minus 5 minutes 59 seconds, and at Noon will be 6 minutes one second. You put your Dial to the right – 6 minutes or $1\frac{1}{2}$ degrees. Now it is telling Local Mean Time, and, to confirm your orientation, you can use the Chichester Sun Compass using the Local Time which the Dial supplies.

Your watch says nearly 6 (G.M.T.). You move 6 on the Ring towards the shadow, and exactly at 6 by your watch you put 6 under the shadow (which is now over 8.26 on the Dial). You have done the famous confrontation of Local and Greenwich Mean Time. On the Ring, opposite to 12 on the Dial, you read your longitude – $36^{\circ} 30'$ East. You are in Russia – only a degree from the longitude of Moscow. There must be something very wrong. Perhaps that pilot was a wrong 'un.

If you don't believe your Clock you can do a sum:

	h	m	s
	12	0	0
Equation of Time –		6	0
	<hr/>		
'E'	11	54	0
Hour Angle ¹	20	20	0
	<hr/>		
Local Mean Time	8	26	0
G.M.T.	6	0	0
	<hr/>		
	2	26	0
	<hr/>		
	= $36^{\circ} 30' 0''$ Longitude East		

Or the story might be different. You find your latitude is 51° North. You think you must be somewhere in Russia and you put 30° East under 12 so as to be ready. It is June 14 – no bother about the Equation of Time. Sun Time is Mean Time too. The Dial says 7.40 a.m. You look at your watch and see that G.M.T. is nearly 8 a.m. There must, you think, be something very wrong. This time when your watch says 8 a.m. you use the other method (see page 114). The shadow

¹ If the longitude is right.

falls on 7.48. Swiftly you move 7.48 (Dial) over 8 a.m. (Ring). Under 12 (Dial) you see on the Ring your longitude - 3° West. You are somewhere in Somerset.

Accuracy

For the particular circumstances of this adventure even my rough instruments would be enough. But the serious navigator will rightly demand a greater degree of accuracy. I demand in return a *vernier* for the reading of the longitude. Whatever method is adopted this will always be shown on the Ring opposite 12 on the Dial. I imagine therefore a vernier attached to the Dial at that point and travelling round with 12 wherever 12 has to go. A fixed magnifying-glass, such as the sextant has, might be a nuisance, and a loose one would be better.

There remains, of course, in the accuracy account, the question of the interpretation of the shadow, which I will discuss later. Subject to that, the mechanical aids I require are four: (a) a micrometer for the height-finder, (b) a micrometer for the latitude-finder, (c) a micrometer to record the Sun Clock's co-latitude, (d) a vernier for the longitude.

I do not suggest that you will often be exposed to such fanciful adventures. They are designed to show that the Sun Clock is afraid of nothing. Starting from 'scratch' you have discovered your geographical position. I humbly ask any expert to name another portable instrument which can do so much so quickly. All you required was:

- 1] The Date
- 2] The Declination and the Equation of Time
- 3] Greenwich Mean Time.

(1) and (2), for a couple of months, can be provided on a single sheet of note-paper. (3) Greenwich Mean Time is now more easily available than ever before. There are magical watches that don't want winding - there are the radio 'pips' - transistor sets, etc. Francis Chichester told me the other day that in the last 'single-handed' race he crossed the Atlantic with no chronometer, relying only on a watch. He also said that all across the ocean he could have got something corresponding to the 'pips' not only on his Radio-Telephone instrument but on an ordinary 'set': but in mid-ocean this would mean getting up in the middle of the night. (I was not clear from what quarter this assistance came - I fancy America.)

That is all. The sextant navigator must carry, besides his sextant, at least two

heavy books, and notebooks in which to do his sums. Some of the 'quick' modern methods are even more onerous. The last one I saw had one volume for four degrees of latitude only, and if you relied on it all the way to the South Pole you would have to carry a library of 14 volumes.

Some Tests

If you do not wholly trust your Clock – and are not too frightened of the Russians – you can sit by it till Noon-by-the-Sun, which, if your Clock is right, should be at 9.40 by your watch (G.M.T.). Set your believed longitude on the meridian line under 12. At noon the shadow should fall on the meridian line (*a*) of the Clock and (*b*) of the Navigator (you lay Protractor *A* flat on its back): and you will be sure of your longitude. If they do not, make an adjustment, and correct it.

While you wait, if you are not satisfied about your latitude you can make some interesting tests:

a] You can *time* the shadow. Note when the shadow falls on 8.15, say, and check it by your watch at 8.45. If the shadow covers more than 30 minutes in that time, that is, your L.M.T. is fast on the watch, your latitude is too high, the co-latitude is too low, and the Dial should be raised a little. If the shadow is slow your latitude is too low, and the Dial should be lowered.

b] How much? the shadow of the 'runner' should tell you. If your latitude is too high it will tend to retire towards the interior of the Dial: if too low, it will go off the Dial (or Ring) altogether. Raise and lower till it returns to its proper place.

(For this purpose I much prefer my 'second style' and the two converging shadows (see page 129). This is more exact, but a bit of a nuisance.)

Limitations to 'the Tricks'

You will not expect, of course, to be able to play all these beneficent tricks at any hour in the day. You must find yourself in the desert at breakfast time, or wait till after lunch, sometimes till tea. By 'the tricks' I mean:

a] 'orienting' the instrument by manœuvring the shadow on *A* on to the Altitude, or, in the second method, on to the Declination. This is the South Trick.

b] recording the rising Altitude on *A* by setting *A* against the Declination on *B*. This is the Altitude Trick.

c] finding the Latitude by using the Declination shadow on *A* (or the 'Apron' on 'Cascanio' - later). This I call the Latitude Trick.

Protractor *A* is facing South, remember, so no shadow can appear on it till the Sun is a fraction South of East. From that moment *a*] and *b*] work at once.

To be on the safe side in all conditions I should advise against relying on *c*] the Latitude Trick later than 0900 Local Time: but well before that you should have all the information you want about your position in the desert. In the afternoon it starts about 3. It seems sometimes to start much earlier - that is, the shadow comes down the protractor and hits the Declination (say, 20° N). But then it goes on down, for a little, and reaches say 18° . Later, when it is in full swing, here is another Stationary Shadow, which stands like a rock on the Declination figure till sundown.

The South *a*] and the Altitude *b*] are really sister tricks. They last, as a rule, much longer than the Latitude, till 10.0 or later. They may begin again at 1.35 or 1.40: but for safety's sake say 2.0. So, except for the central four hours, you can find the South without the compass all day. These two tricks, of course, can be checked at any time with the Height-Finder.

At about 2 hours before noon a new set of tricks takes over. There are the Stationary Shadows. There is the Noon Altitude Trick, which I have discussed under Height-Finder. This trick can be better done with the Navigator (or Cascanio - later). If it could be made accurate it could be a Latitude-Finder: for *A* points to the noon zenith distance, and if you add the Declination (in Summer Time, at Hammersmith) you have the latitude.

It would be foolish for a mere amateur to be too certain about anything: but whether it comes to anything or not all this harnessing of Altitude, Declination and Latitude is fascinating fun. One expert said that I was probably lucky to be so near to the Latitude of 45° . That may be so: but these tricks are merely manipulations of the same Spherical Triangle, which, I should have thought, could be made to play, in the same sort of way, almost everywhere.

There might be differences at different times of the year, and with different Declinations. But I have not confined myself to the summer or to low Declinations. I see I did the Latitude Trick successfully at 8.45 G.M.T. on December 20, 1964 - Declination $23^{\circ} 26' 12''$ South, and at 8.15 on February 14, 1965 - Declination 13° S.

The tricks are partly curiosities, and partly advertisements of the instrument's

capacity. They will only be practically useful perhaps, in the early stages, if, like the man in my story, you are absolutely lost, and have no faith in your compass. The best, and permanent, check, both on orientation and Latitude, will be the shadow of the runner (or, better, the two shadows) on the rim.

CASCANIO

or Compass and Sextant, Clock and Navigator In One

This is a compendium, amalgamation, or assembly of the three new instruments we have discussed in Part Two of the book – the Height-Finder, the Navigator, and Sun-Clock. All these are concentrated, in the only two models I have made, into a circle of hardboard 8 inches in diameter, and the highest point is never more than 6 inches. It could be packed in a box 10 inches by 8 by 3. My sextant, with all its telescopes and padding, is in a box measuring $10 \times 10\frac{1}{2} \times 5$ inches. My Star Globe is in a box 10 inches by 10 – and 11 inches high. My Bubble Sextant, without its box, is about 8 inches by 8, and $8\frac{1}{2}$ inches high.

Cascanio may be too small for prime efficiency, but I was governed by the size of the largest semi-circular protractor I could get, which is 6 inches long and 3 inches deep. Also, I was thinking of the explorer more than the mariner. The mariner can have a bigger one.

The circular base, as I have said, is 8 inches in diameter, painted white, and marked at the rim with the points of the compass.

It has, as usual, a meridian, North and South, line, and an East-West line intersecting it at the centre of the circle. On the meridian line is, again, a semi-circular protractor, perpendicular. We will call this *B*, as in the Height-Finder. On its right again, as you look South, that is, on the West side, is another protractor, facing South and hinged to the base at right angles to the centre of *B*. It is a whole circle. We will call this *A*, as in the Navigator.

On the other side of *B* – that is, the left or Eastern side – is a small edition of the Sun Clock facing North. This we will call *C*.

A and *C* are quite independent, but both are served by *B*. Both, for accuracy, should have the assistance of a micrometer. In that case protractor *B* would not be wanted. Having no micrometer I use needles stuck in the edges of *A* and *C* just above the curve of *B*.

The Sun Clock (C) in this amalgam has a new feature which I will call the *Apron* (D).

This, as you can see in the picture, is one more (small) semi-circular protractor, which is fixed facing South, at the top of the Sun-Clock's plane, with the straight edge upwards. At the centre of the straight edge is a needle-style (the professionals, no doubt, can provide something as slender but more secure - and hinged).

(1) *Orientation*

There should be a small compass somewhere on the base, for the instrument is self-southing and will check your compass and the local 'variation' for you.

First, set *A* with its edge opposite to the Declination on *B*.

Then, get the Altitude. For this purpose we use *C* and its Apron as our Height-Finder. Turn the instrument towards the Sun till the style on the Apron shows no shadow. The edge of *C* will then be opposite the Altitude on *B*. Now quickly turn the instrument to the right, Southward, till the shadow on *A* falls on the angle of the altitude you have just obtained.

You should now be oriented. But you can check this with *C* and the Apron. Move *C* till it is opposite the angle of the Declination on *B*. The shadow on the Apron should then show the Altitude, and confirm the verdict of *A*.

Till about 9.30 or 10 (in this latitude at least) *A* and the Apron, if you leave both as they are, will record the rising Altitude together; and if they do not agree an adjustment is needed.

(2) *Latitude*

But you want to get on.

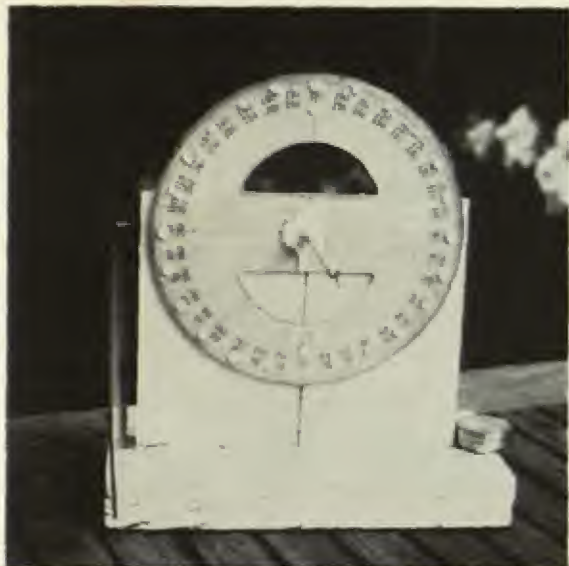
a] as we did with the Navigator, move *A* till the shadow falls on the angle of the Declination and the edge of *A* will be opposite to the Latitude on *B*. (This is what I call 'the Latitude Trick'.)

b] move *C* till the Apron shadow falls on the angle of the Declination, and the edge of *C* will be opposite to the Co-Latitude.

The Sun Clock is ready for action.

(3) *Longitude*

Find the Longitude as I have explained already (page 114).



13. THE NAVIGATOR facing East – a 'stationary shadow' – showing the Noon Altitude, before Noon.

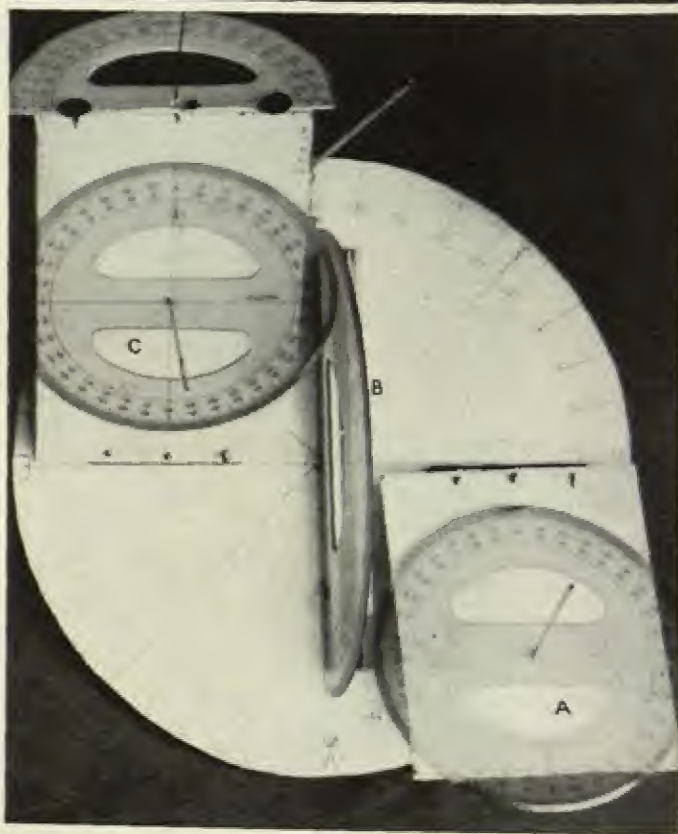
14 below. SUN CLOCK artificially arranged to show second, Declination, shadow, on the left.



15a. CASCANIO from
the East.



15b. CASCANIO from
the North. A on the right
- C, Sun Clock facing
North on the left.
Note the Apron, left.



Double Cascanio II. The second model I made is an improvement in principle. The protractors, etc., as described, are on a separate floor, smaller than the main base: and can be swivelled round without disturbing it. The advantage of this is that when you have 'southed' the whole thing you can at any time turn *C* and get the altitude of the Sun without losing your hard-won 'orientation'.

The Spherical Triangle

If the mariners and the explorers reject this instrument for practical purposes they will admit, I hope, that it would be invaluable for the education of the young. You can play with the mechanism of the Spherical Triangle as you play with the stops of an organ. On Protractor *B*, at this moment, you can see *PX* before your eyes and on *A* the shadow shows *PZ*. Now move *A* till it points to the Declination on *B*, and the shadow will show not only the changing altitude but the changing *ZX* as well. Here is the whole of the famous Triangle.

If you knew your latitude and the altitude but not the declination, you could:

a] set *A* opposite the latitude on *B* and the shadow on *A* would show the declination.

b] set *A* so that the shadow fell on the altitude and the edge of *A* would be opposite the declination on *B*.

It is mostly more convenient if you want to record the moving altitude to reckon the declination from the top centre of the Protractor *B* instead of from the bottom.

STATIONARY SHADOWS AND OTHER TRICKS

If in a pub you said: 'I bet you I can cause a shadow which won't move for an hour or more' you would get many takers and make good money: for all men know that shadows, like the Sun, are never still. But I can make a shadow stand on or about the same line in three or four ways - sometimes for three or four hours and more.

These are mysteries which I must leave to the experts to explain, and to develop, if worthy; but it may be useful to record my experiences.

(1) *Reversing the Sun Clock*

I stumbled on the first almost by accident. In curiosity, I suppose, I turned the Sun-Clock, properly set out for the Latitude $51^{\circ} 30'$, so that it faced the wrong way, due South. The style threw a shadow at an angle which turned out to be the declination, and seemed to dwell for some time. On this I would certainly win a bet (if the pubs were open between 8 and 9). This shadow is the foundation of the 'Latitude Trick', described on page 170.

(2) *The Noon Altitude Shadows*

These, I feel, may be more important.

a) I mentioned the first when explaining the Height-Finder. From about two hours before noon - but more effectively, perhaps, about half an hour later - turn the Height-Finder Southwards, not Sunwards, and raise it till the shadow falls on the East-West line on the Disc. It will remain there or thereabouts, shortening always, till it disappears into the style. After noon it will appear on the same line on the Eastern side of the style, and remain there for as much as two hours more. All this time the edge of *A* will be pointing (on *B*) to the altitude of the Sun that will be (or was) at Noon-by-the-Sun. I have already mentioned the possible advantages of this peculiarity. The shadow may slowly shift, North of the line in the morning, and South in the afternoon, especially with a high Declination: but so far as can be told with my instruments the original reading is pretty accurate, and nothing like two degrees out. It is certainly near enough to be very helpful in the Sahara. If there is a predictable error, at this or that time or Declination, the astronomers must work it out for me, and suggest the correction.

b) The same can be done with the Apron on *C* in Cascanio.

c) Move *A* - either in the Navigator or Cascanio - till the shadow falls on the East-West line and the edge of *A* will point (on *B*) to the Noon Zenith Distance (and Altitude) for the same period.

d) is quite different. Pull up *A* in the Navigator till it stands at 90° , with the style parallel to the horizon, and face the instrument due East. Again, for the same periods, the shadow will mark the Altitude at Noon (after noon, of course, you will have to turn it so that it faces due West).

Navigation apart, I have sometimes brooded over some practical application of this discovery. If a knitting-needle, pointing East and parallel to the horizon, will

throw a steady shadow however much the Sun moves, so, I presume, but much more, would a plane surface in the same position. Some people, though they love to see the Sun, hate to sit in it – old ladies, for example. In parks and private gardens there might be special seats facing East, West, and, I suppose South, guaranteed to be in the shade for stated periods. The Mediterranean artist is often driven too soon from his labours by the burn of the Sun. Whatever walls he chooses to protect him the Sun always comes round, or over, them in the end. He might carry a light personal harness which would protect him all the morning or afternoon, so long as he chose his subjects wisely. Then – though this is more difficult – you might arrange for a stationary shadow on your unfriendly neighbour's tomatoes.

(3) *The Herbert Compass*

This, too, depends on a stationary shadow – the shadow thrown on a plane surface facing South by an object emerging from it at the angle of the latitude – or of the latitude plus the declination. It is certainly stationary for long periods, but, as I have related, I am not in all conditions satisfied with it.

(4) *The Stationary 'Spot'*

On one of my multiple Dials – Vertical, Horizontal, and Elliptical – I have rather roughly arranged a spot-light altitude recorder. The degrees are marked on the centre of the wall of the Vertical. The little mirror is near the base of the style. To get the altitude you must turn the instrument towards the Sun. But when it is in its normal position, facing South, it seems to me that from about 10 the spot-light – away out to the side – is on the line of the noon altitude. I have not had the time or the conditions to pursue this thoroughly. Here, perhaps, is another avenue for experiment.

THE AIR

Now, what about the Air? I approach this theme with due apologies. I have no first-hand experience of air navigation. But generous masters of the art have told me something about it. I think it unlikely, I confess, that supersonic monsters like the *Discord* and the *Shooting Star* will ever use the Sun Clock to find out where they are: but let me assert firmly that if they had to use the Sun it would serve them well. High speed would not frighten the Clock: indeed, the higher the speed the greater would be its advantage over some other methods of using the Sun.

But these manned meteors will not use the Sun at all. For one thing, like owls, they will do most of their flying by night. For another, they will be equipped with one of those more than magical 'inertial' systems, fantastic assemblies of gyroscopes and accelerometers and monitors and Doppler devices, which measure speed by noise, and God knows what. With all this wizardry they will be able to read off instantaneously their latitude and longitude, and much besides, as you read a cash register or petrol gauge. So I can only say that if the Prime Minister said: 'You can have the *Discord*, but we can't afford all these gyroscopes and things. Also you're waking the world up - you must go about by day' - the Sun Clock, also instantaneous, and taking up less room, will be available.

By lesser breeds of aircraft the Sun is still employed, in addition to the network of radio 'beams' and beacons which assist them. The old projecting 'dome' in which sextant sights were taken has been sacrificed to the great god Speed. In time, I suppose, 'streamlining' and 'pressurizing' may make the use of the Sun impossible. But even the *Concord*, I see (in a 'mock-up'), will have two windows on each side of the flight-deck. It would be a deplorable conclusion to Man's lordship of the Heavens if his heavenly masterpieces had to exclude the Monarch of the Heavens and go about like bats with their eyes closed. It would be a pity too, if, intoxicated by 'electronics', he quite abandoned Nature and threw overboard all the lore of the heavenly bodies. Gyroscopes and 'Beams', I suppose, may falter or fail: and there is never any harm in checking. So I was glad to hear that 'Astro-Navigation' continues.

They pursue both Sun and stars with a clever 'periscope-sextant' poking its nose out of the aircraft. Then, to work out their 'sights', they use one of those Short 'Tabular' Methods for Solving Observations of Celestial Bodies. In all these 'short' methods 'some assumed position must be selected' - a Latitude and a Longitude. (The Sun Clock has to assume nothing.) Then you must search in the Tables for figures - sometimes 5-digit figures, as bad as logarithms - giving the appropriate values of L and A and B and C and Z' and D and K , add A to B , and C to D and Z' to Z'' and so on. All this takes time and has to be written down. You have already done as much preliminary paper-work as you would do with the old-fashioned methods of 'logarithmic computation': and now you have to draw a plan, in the same old way, to find out what your 'short tabular method' has revealed.

The case for the defence is (a) that they do all the preliminary work at leisure

in readiness for a certain time (as they do at sea), (b) the drill is easily learned, (c) they can get a final result 2 minutes after the final sight is taken, (d) that the result is accurate to about 7 miles. The case for the Sun Clock is that it is at least 2 minutes ahead of the short swift method, and, in hard fact, much more. For no 'preliminary work' is necessary, no looking up in books, no writing down or adding or subtracting. No 'certain time' is necessary: any time will do. No 'position' has to be 'assumed': the Sun Clock knows it. Over any point in the Atlantic, if the Captain says 'Where are we?' the navigator will glance at his chronometer, put Greenwich Time (on the Ring) under the shadow, and read his longitude under 12 at once.

His latitude, if the instrument is properly made, will be recorded by the micrometer attached to the dial. But he will know this already. Flying East or West, say, between London to San Francisco, there will be a slow but steady change of latitude. The shadow of the 'runner' will advise him of this by moving off the edge of the Ring, one way or another. So he will keep an eye on the shadow and continually make small adjustments which will keep the angle of the dial (the Co-Latitude) correct. For this purpose, in a professional job, I would prefer to have my 'second style' and the two converging shadows (see page 129). The effect is more precise and swift. The moment the two shadows separate, or cross, something is wrong, and must be corrected. The rigging of the second style may be a nuisance for the amateur but would be a trifle to the professional.

There should not, in a well-found aircraft, be any trouble about the orientation. For example, the Clock could rest on a Pelorus, set for the ship's course. But, if there were, the two shadows would again give warning. The Clock, of course, will be disturbed by 'turbulence' – but so is the sextant, especially the Bubble Sextant, with which I have worked. It must have Sun – but so must the sextant. I merely say that experiments with a properly constructed Clock would cost Britannia very little and might be instructive.

With these, and other, due reservations I have sketched roughly, a voyage of the *Discord* to San Francisco and back. It is technically nonsense, I know, for I have assumed (a) that she flew at a uniform speed from door to door, not allowing for 'subsonic' climbing and descending and (b) that she flew 'straight' to her destination across one of Mr Mercator's maps. My object is to keep the picture simple, and to show the student how the Sun Clock would respond to such alarming conditions.

The difference of latitude between London and San Francisco is $13^{\circ} 42'$ - London $51^{\circ} 30'$ North and San Francisco $37^{\circ} 48'$ North ($122^{\circ} 25' W$). The mean length of a degree of longitude in those latitudes I make 42 miles; so without going into Great Circle sums (of which I am not a master) I reckon that she has to cover 122 degrees of longitude and 5124 miles. I give the *Discord* a man's speed of 1470 m.p.h., with which, I reckon, she will cross 35° of longitude every hour.

She leaves London at 0900 G.M.T. - and Local Mean Time too. But the inferior Sun covers only 15° of longitude in an hour, so the shadow, showing Local Time, goes back, and she wakes up the poor Mormons at Salt Lake City at 4.48 the same morning.

OUT

G.M.T.	Longitude	Shadow shows S.M.T.
9 a.m.	0°	9 a.m.
9.16 "	$9^{\circ} 36' W$ Fastnet Light	8.37 "
10 "	$35^{\circ} W$	7.40 "
10.49 "	$64^{\circ} W$ Nova Scotia	6.39 "
11 "	$70^{\circ} W$	6.20 "
11.17 "	$80^{\circ} W$ Montreal	5.57 "
12 noon	$105^{\circ} W$	5.0 "
12.12 p.m.	$112^{\circ} W$ Great Salt Lake	4.48 "
12.26 "	$120^{\circ} W$	4.26 "

The navigator will be undeterred. He will keep an eye on the chronometer and from time to time move the appropriate G.M.T. (on the Ring) under the shadow. Then without one book, assumption or calculation he will see his longitude (on the Ring) under 12 (on the Dial).

On the voyage home the shadow will hurry forward, drawing nearer to Greenwich Time all the way. In every hour by the watch it covers 3 hours and 20 minutes by the Clock.

HOME

G.M.T.	Longitude	Shadow shows S.M.T.
1500	$120^{\circ} W$	0700
1600	$85^{\circ} W$	1020
1636	$64^{\circ} W$ Nova Scotia	1220
1700	$50^{\circ} W$	1340
1800	$15^{\circ} W$	1700
1810	$9^{\circ} 36' W$ Fastnet Light	1731
1826	$0^{\circ} 0' W$ London	1822

She takes one hour and a half, observe, to cross from shore to shore.

About the practicalities of using a Sun Clock in the air I cannot advise. But 'where there's a will' as somebody has said 'there's a way'. They must have a Sun Deck somewhere.

I see, by the way, that one of the three Russians who did 16 orbits in the *Voshkod*, October 1964, used a sextant: 'Feoktistov, sextant in hand, asked the captain to change the *Voshkod's* direction in such a way that some constellation stayed as long as possible in view from the porthole.'

If everyone is not very careful I shall sell the Sun Clock to the Russians.

PART THREE

The Shadow

The Shadow

I come now to a very important question, the merits of the shadow, and the technique of its interpretation.

Serious mariners are inclined to be sniffy about the shadow – 'too wide, too woolly' and so on. But then, they have never worked with the shadow. They are accustomed to the sprawling shadows on the rose-garden pedestals, or the walls of churches, or the long furry shadows thrown by the flag-staff at the barracks. They have never seen the sharp small shadow which is thrown by one of my silken threads. This is no bigger than my markings on the Dial, or the marking of a degree on a protractor. I can cry 'On!' with confidence when it hits the hour or the quarter – though, of course, without a vernier I cannot swear to the intervening minutes and seconds. A silken thread, I agree, is difficult to rig on such instruments as the Sun Clock (it is easy for the Vertical cum Horizontal): and I have too often to be content with needles. But modern industry, I am sure, if requested, could give us steel styles more slender than a thread, and hinged at the bottom too, for easy packing. No doubt, as I have said before, very similar objections were made about that furry fellow the Sun in the early days of the sextant. The sextant notes and records a single instant in the Sun's day. So does the Sun Clock, and the exercise of similar care and skill may give similar results. At least, the effort might be made.

But here we must distinguish, as I have tried to do all through this book, between the needs of the garden or the church and the needs of the traveller abroad. For Part One diallers I do not fear a shadow wider than scientific accuracy would like. They should not be made to peer, as we do at a thermometer or sextant. They want the time to be accurately told; but for most purposes they will be content to read it roughly at a reasonable distance. We are all proud of the accuracy of the great Clock at Westminster, erroneously called Big Ben (which is, strictly, the name of the master Bell): but do we often care if it says 6 or 7 minutes to? For these the shadow of my silken thread will be far too slender.

This sort of thought, no doubt, was in the minds of our ancestors (though not

when they made that illegible thing in the rose garden). That big shadow on the church wall gave the people the rough idea – and it had the advantage that when any part of it touched the right hour the awed and ignorant said: ‘Oh look! it’s right.’ But in their smaller pieces they overdid it. They recognized this. Not every writer frankly faces the question: ‘Which part of the shadow is supposed to tell the time?’ Tradition, I believe, says: ‘The *outside* edge on either side of noon.’ The sage of 1820 confirms it. He says:

It is necessary to observe, that if a dial be made according to the strict rules of calculation, and truly set at the instant, when the sun is in the meridian, it will be a minute too fast in the forenoon, and as much too slow in the afternoon, by the shadow of the style; *because the edge of the shadow that shows the time is even with the foremost edge of the sun in the forenoon, and with his hindmost edge in the afternoon, on the dial*, whereas the sun’s *centre* determines the time in the (supposed) hour circles of the heaven: and as the sun is half a degree in breadth, he takes two minutes to move through a space equal to his breadth; and there will be two minutes at noon in which the shadow will have no motion at all on the dial. It likewise appears, that if the dial be set true by the Sun in the forenoon it will be two minutes too slow in the afternoon, and *vice versa*.

The way of remedying this error is to set every hour and minute division on the dial *one minute nearer XII* than the calculation requires.

‘With great respect’, as the lawyers say, to the Sage, I find this feeble. Why mutilate your scientific instrument in order to correct an error which you have yourself unnecessarily created?

The learned Mr W. Richards, in the ‘Appendix on Construction’ which he contributes to Mrs Gatty’s book, also lends himself to mutilation. He recommends *two* perpendicular lines for Noon. ‘Mark its distance’ (the second line) ‘from PS equal to the width of the gnomon. This double line is called the substile or substyle.’ To provide for this they draw not one circle but two semi-circles on either side of the substyle, and they draw their hour-line angles from *two* centres, on either side again. So the substyle was a sort of neutral territory, and seems in the plan to be about 2 degrees wide. Yes, but what happened at Noon? The Sun had to cross the neutral territory before the shadow could start work again: and no wonder if in the afternoon it seemed to be ‘slow’.

I may not fully understand these arrangements but I am sure they are not to be recommended. The right way seems obvious:

a] For garden and ordinary purposes have a style and shadow as thick as you desire, for this reason or that: but tell yourself always – and tell your family and friends – that it is the *centre* of the shadow that represents the centre of the Sun and, as the Sage puts it, ‘determines the time’. This must be right. Suppose you have a tapering style – a pencil with a pin stuck in the end of it. In the early hours you will see only the shadow of the pencil: at noon and earlier you will see the slender shadow of the pin and you will use that as your marker. But if before that you have been using the edge of the *pencil* shadow you will ‘go to leeward’ as the sailors say. For ordinary purposes it is easy enough to work to the centre of the shadow. If you are not satisfied use the edge but scientifically. Say the semi-diameter of the Sun (according to your Almanac) is 16' today. That means 1 minute and 4 seconds. Take the time (by your second-hand) when the inside edge of the shadow touches an hour-line. After 64 seconds you can say ‘Bang! that’s centre.’ Otherwise, have nothing to do with edges: and never, as the Sage suggests, mutilate your markings.

b] if you want anything like navigational accuracy have a style as slender as possible. My silken thread shadow poises over an hour-line and is gone like – well, like the Sun.

But perhaps we can do better. Optics is not one of my subjects, but could we, I wonder, call in the aid of sunlight which, *ex hypothesi*, is present at the time? Mr Richards in Mrs Gatty’s book writes:

There is a fine example in the Guard House at the Palace of the Prince of Monaco, and there the end of the gnomon is flattened out to a disc with a hole in the centre having knife edges, and when I saw it the bright sun of Italy cast a clear spot of light about the size of a shilling on the lines of the curve, which, as well as the hour-lines, were about $\frac{3}{4}$ inch broad. The sundial itself must have been 13 or 14 feet high.

The *American Navigator* says: ‘In some rings for observing azimuth of the sun advantage is taken of the brightness of that body to reflect a *pencil of light* upon the card in such a manner as to indicate the bearings.’

If we are not content with the shadow (I am making no complaints myself) a ‘pencil of light’ may be the thing. But it must be available at any point of the

lower half of the Clock, not merely on the noon-line, as, I gather, is the spot of light at Monte Carlo.

Long ago, I made some rough, unskilled experiments myself:

a] a single needle throws a small sharp uniform shadow for about 5 inches: but on any scale it seems to fill nearly half a degree. But I tried a style consisting of two needles, with a small space between them. The lighted slit in the shadow was clearly visible at 5-6 inches from the style, and seemed to be smaller than the shadow of a single needle. (The style could be rotated when the slit-effect was desired.)

b] A magnifying-glass (the vernier glass from a sextant) held close to the style, and between the style and the Sun, reduces the shadow (at short ranges) to a tiny thread in a pool of light. Farther from the style the shadow is killed by the light: but the pool of light becomes an elongated ellipse, ending in a point.

c] the shadow if made to pass through the same glass (held on the dial) is not so strong but becomes sharper and smaller. It now seems to occupy about a quarter of a degree.

d] the same glass held *over* the shadow strengthens and sharpens it.

e] a *reducing* glass (from the sextant box too) makes the shadow much smaller, sharper and stronger.

There may be nothing in these elementary fumbles, but I have not the resources to do more. They have put in my mind two or three possibilities, though, on which an expert, no doubt, can easily pass judgment:

a] a low fence of appropriate glass - or plastic - round the outer part of the dial (between the style and the markings) to refine and reduce the shadow on the rim, or perhaps convert it into a 'pencil of light'. There should be no distortion for each beam will hit the fence directly.

b] a double style (rotatable) with a slit fitted with appropriate glass which would have the same effect.

c] a magnifying - or reducing? - glass fixed, like the glass of a sextant, but with a flexible arm which could follow 12 wherever 12 went.

I hope I have said enough to persuade some who matter that my instruments have merit. If they deserve attention they deserve assistance. They are by no means perfect: but I can do no more. Respectfully, I call 'Technology' to my aid.

Practical Hints (Miscellaneous)

Levels. Verticals seem especially sensitive to a faulty level. A sort of rule to remember is 'The rise repels the shadow'. So if your Vertical is too high on the right the shadow will be slow: if it is too high on the left the shadow will be fast. Hang a small plummet on a thread from the top of the style.

Marking. However carefully you make those dots at the edge of a protractor (if you use that method) there may be error. Before you finally mark your hour-points measure, with the dividers, intervals which ought to be the same on either side of the meridian line, e.g. - 11 to 12 and 12 to 1. If they are equal all should be well: if not check your dots again. Do this for every hour-point.

Conscious of the possibility of human error though you may be, once you have made your markings, you may tend to put too much faith in them. When the shadow is fast or slow at 9.45 you may say 'Oh, dear!' and start pushing the instrument about, forgetting that it may be a faulty marking. Wait, at least, till 11 which is more likely to be an accurate marking. Better still, wait till 12.

Styles. For the Horizontal or Vertical I much prefer the rod or pole type of style (the sawn-off knitting-needle, or a steel pin, for example) to the triangular wooden affairs. But it is not always easy for the amateur to fix a rod at exactly the right angle securely. I have found a useful compromise. Make a small triangle of wood with one angle the same as the latitude. Then make a groove down the south side of it into which the needle fits. Glue the triangle firmly to the dial with one of those strong sticky preparations, and the knitting-needle to the groove. Then paint the whole contraption white - in oils.

Another trick, with a small dial, is to mutilate a protractor. Cut across it at the right latitude angle; insert the South end into a groove in a small horizontal piece of wood (to keep it vertical), stick it to the dial on the meridian line - and paint. With this, by the way, you can test the Herbert Theory of the Miracle of Isaiah, by laying another style alongside.

Materials. In these islands it sometimes rains very suddenly. You leave a sundial under a bright blue sky and go into lunch, and half-way through the meal there is a deluge. If you have used oil paint and indelible ink you can sit still. But it is

tempting to use, say, poster paint, which dries quickly and takes writing well, and a ball-point pen which throws no blots. Then quite a small deluge will ruin your work. I used to think that a ball-point was waterproof, but I know one at least that 'runs'. So, in the end, does the paint. When you are beginning and not quite sure of yourself use a pencil and any paint or no paint at all for your experiments. But afterwards oil and indelible, enduring bravely the long wait for drying and the anxiety about blots.

We cannot all afford brass plates, or acquire wood that never warps. To the beginner I recommend hardboard for the dials. I get a local wood-man to cut circles of hardboard, of prescribed diameters (this is the only thing I do not do myself). Six inch is a good diameter to begin with. Draw a Horizontal in the Northern semi-circle, the style in the centre, and an Elliptical in the Southern half. Then you have a small but neat 'self-souther'.

If sundials multiply as I hope I see a fine new opening for the plastics world. In my experience these materials stand up to the Sun extremely well. In one of my instruments I exposed the cheapest kind of protractor to the hot Mediterranean Sun nearly all day for three weeks. It wilted not at all. My Star Clock, made of ivory perspex, and beautifully engraved by 'Marine Instruments' of Fenchurch Street, must be at least 20 years old. I do not leave this about in the Sun but it has spent many months in the hot chart-room of a yacht (not mine) in the Mediterranean. It looks as good as new and has warped not a millimetre. The plastics world should make some experiments.

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